MESH 2012

The Fifth International Conference on Advances in Mesh Networks

WMHLH 2012

First International Workshop on Wireless Mesh Networking for Human and Livestock Healthcare

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MESH 2012

Foreword

The Fifth International Conference on Advances in Mesh Networks [MESH 2012], held between August 19-24, 2012 in Rome, Italy, built on the previous editions to address the most challenging aspects for designing and deploying mesh networks.

The wireless mesh networks came to rescue the challenging issues related for predicting the location of a user and choosing the position of access points in wireless distributed systems. Basically mesh networks guarantee the connectivity through a multi-hop wireless backbone formed by stationary routers. There is no differentiation between uplink and downlink, but performance depends on the routing protocols. There are several challenging issues for properly exploiting wireless mesh networks' features, such as fast-link quality variation, channel assignments, performance, QoS-routing, scalability, slow/high speed mobile users, service differentiation, and others.

MESH 2012 also featured the following workshop:

- WMHLH 2012, First International Workshop on Wireless Mesh Networking for Human and Livestock Healthcare

We take here the opportunity to warmly thank all the members of the MESH 2012 Technical Program Committee, as well as the numerous reviewers. The creation of such a high quality conference program would not have been possible without their involvement. We also kindly thank all the authors who dedicated much of their time and efforts to contribute to MESH 2012. We truly believe that, thanks to all these efforts, the final conference program consisted of top quality contributions.

Also, this event could not have been a reality without the support of many individuals, organizations, and sponsors. We are grateful to the members of the MESH 2012 organizing committee for their help in handling the logistics and for their work to make this professional meeting a success.

We hope that MESH 2012 was a successful international forum for the exchange of ideas and results between academia and industry and for the promotion of progress in mesh networks.

We are convinced that the participants found the event useful and communications very open. We also hope the attendees enjoyed the historic charm Rome, Italy.

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Table of Contents

Method of Dynamically Determining the Nodes that Hold Advertisements Suitable for the User's Preference and a Relay Routing Method Based on Area Division

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Abstract—**Mobile communications carriers are providing GPS-based, location-dependent advertisement delivery services as supplementary services. As the number of mobile terminal types and the number of mobile users increase, the need is rising for a network that can handle location-dependent traffic within a locality efficiently. This paper presents an ad hoc network for location-oriented advertisement delivery, with an advertising node installed in each shop in a busy shopping area. Specifically, it describes a way to express the user's preference, such as their hobbies, based on a Bloom Filter, and a way to dynamically determine the nodes that hold advertisements suitable for the preference of the target user. In addition, the paper also presents a routing method based on area division, which can reduce the number of relay nodes. It has been confirmed, by using simulation, that the proposed method reduces the number of relay nodes by about 70% compared with a case where messages are unicast to collect suitable advertisements.**

Keywords-location-dependent advertisement delivery; ad hoc network; user's preference; bloom filter; routing.

I. INTRODUCTION

As mobile terminals and one-segment broadcasting become widely used, a system has been proposed that delivers advertisements of shops to nearby pedestrians using weak radio waves for one-segment broadcasting. However, a network that interconnects shops and a system that delivers advertisements of multiple shops close to the target pedestrian are yet to be implemented. A service is being provided, in a wide-area network, in which the advertisement delivery server receives GPS (Global Positioning System) data of mobile terminals and sends by email those advertisements of shops that are judged to be suitable based on the locations of the pedestrians and their pre-registered preference data [1]. However, despite of the fact that delivery of advertisements is confined to a certain locality, the delivery traffic is centrally handled by the possibly remote advertisement delivery server that covers a wide area. As such, the rapid growth in access traffic and the number of smartphones are increasing the traffic load on the core network. To simplify the traffic design of the network, service providers are increasingly using public Wi-Fi LANs (Local Area Networks) [2], which are provided by installing Wi-Fi access points at cafés and other types of shops. If an advertising node is installed at each access point and these nodes are interconnected in a network, regionally confined advertisement traffic can be handled locally. Since different shops have different business hours, this network must be configured dynamically so that it will interconnect the nodes of only those shops that are open. A wireless ad hoc network is suitable for this purpose. Routing protocols that have been defined by IETF as RFC for an ad hoc network include OLSR (Optimized Link State Routing), AODV (Ad hoc On-Demand Distance Vector) and DSR (Dynamic Source Routing) [3]-[6]. In addition, there are reports of protocols that extend these and incorporate the concept of link life [7]-[9]. However, it is necessary to study an application-level routing method suitable for providing an advertisement delivery service in an ad hoc network.

With a view to building an ad hoc advertisement delivery network, this paper proposes a way to dynamically determine nodes that hold advertisements suitable for the target pedestrian, and a routing method based on area division, which reduces the number of relay nodes. Section II discusses the conditions for providing an advertisement delivery service in an ad hoc network, and issues for implementing this service. Section III describes a way to express the user's preference based on a Bloom Filter, and a way to dynamically determine nodes that hold the suitable advertisements. Section IV presents a method of selecting efficiently routes to the nodes holding advertisements suitable for the pedestrian's preference in order to reduce ineffective traffic handled by advertising nodes. Section V describes a simulator developed to examine the proposed method, and how the proposed method reduces the number of relay nodes. Section VI describes the related works. Finally, Section VII gives conclusions and future issues.

II. AD HOC ADVERTISEMENT DELIVERY NETWORK

Busy shopping districts are often formed near train stations, with shops patronized by commuters and students. Districts with many specialty shops are also formed in other areas where people gather. In addition, when there is a special event, such as a festival at a shrine, many temporary shops open at the event site. The shops in such an area cooperate with each other, forming a shop owners' community. This paper assumes that each shop in an area has an advertising node, and that these nodes form an ad hoc network, as shown in Fig. 1. Each advertising node has

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information about the locations of all the advertising nodes in the area. It also holds the data on the advertisement types held by each node in the form of an Ad Filter (AF), which is generated using the Bloom Filter (BF) algorithm [10]. Data about advertisements are collected in this network in the following steps:

Step 1: The pedestrian registers his/her preference information in his/her mobile terminal in advance. The mobile terminal generates a Preference Filter (PF) from that information using the BF algorithm.

Step 2: The mobile terminal puts the PF in an advertisement acquisition message (AAM) and sends it to the advertising node closest to the terminal.

Step 3: The node that has received the AAM compares the PF in the AAM with the AFs of all the nodes in this area, and determines the nodes that hold the AFs that are suitable for the PF.

Step 4: This node determines the optimal route to pass the AAM to all the selected nodes, puts that routing information in the AAM, and sends the AAM to the next node.

Step 5: The advertising node that has received this AAM compares the PF in the AAM with its own AF to determine whether it holds an advertisement suitable for the pedestrian.

- 5-1: If it determines that it does not have such an advertisement, it passes the AAM to the next node designated in the routing information in the AAM.
- 5-2: If it determines that it does have such an advertisement, it sends that advertisement to the user, and passes the AAM to the next node designated in the routing information.

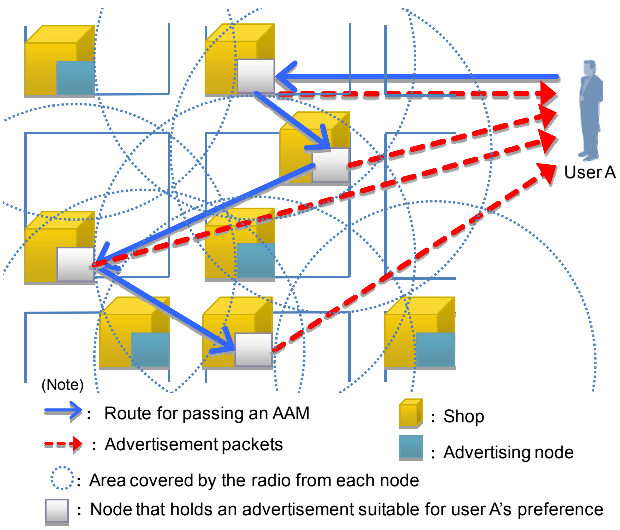

Figure 1. Example of an ad hoc advertisement delivery network.

To build an ad hoc advertisement delivery network, such as the one shown in Fig. 1, this paper address the following two issues:

Issue 1: How to generate a PF and an AF using the BF algorithm

A PF and an AF are generated using the BF algorithm, which can compare filters at high speed, and can express the elements of the user preference data and those of the advertisement data held by each node with small data. To generate these filters, it is necessary to specify the elements of the PF and to determine the bit array lengths of the PF and the AF taking the false positives of the BF algorithm into consideration.

Issue 2: How to determine the route that minimizes the number of relay nodes

To reduce the routing overhead in acquiring advertisement information in an ad hoc network, it is necessary to find a routing method that minimizes the number of advertising nodes that only relay advertisement information.

III. Elements of the PF and the AF and the Logic for Generating and Testing These Elements

A. Elements

To make it possible to check a match between an advertisement information and the user preference information, an element set, D, is defined as follows. The elements in D are the basic user data, such as the user's gender and job. An element, d, is defined as a combination of the element name, d_name, and its value, d_value. This definition allows two elements with the same element name but different values to be handled as different elements.

$D=\{d_1, d_2, \cdots, d_n\}$, where d_i=(d_i_name: d_i_value).

To enable the user to express different aspects of his/her preference, and the advertisement provider to select potential receivers of their advertisements from different perspectives, the following element names have been defined: gender (gender), date of birth (year, month, day), body-mass index (bmi), job (job), annual income (income), whether married or not (partner), whether the user has a child or not (child), child's age (child_age), and hobby (hobby). Examples of element values are shown below. The number of elements, *n*, is 17. The element values for job have been defined in advance.

D={gender:0, year:1988, month:5, day:21, bmi:1, job:14, income:0, partner:0, child:0, hobby:1, hobby:9, hobby:10, hobby:17, hobby:18, hobby:19, hobby:20, hobby:21}

Elements are classified into two categories: those in the main element set, D_m, and those in the sub-element, D_s. D_m includes gender, job and hobby, which do not vary greatly from user to user. On the other hand, D_s includes date of birth, annual income and child's age, which can vary greatly. Thus,

$D=\{D_m, D_s\}$

D_m={gender:0, job:14, hobby:1, hobby:9, hobby:10, hobby:17, hobby:18, hobby:19, hobby:20, hobby:21}

D_s={year:1988, month:5, day:21, bmi:1, income:0, partner:0, child:0}

If elements for a filter are to include all the elements in D_m and D_s, the users at whom an advertisement is targeted will be extremely narrow, and the BF's advantage of high data efficiency will be reduced. Therefore, we have decided that the PF and AF, which are used to check a match between an advertisement information and the user information should contain only D_m. D_s is used by advertising nodes to determine whether it should store a specific advertisement or not. This paper does not consider this aspect.

B. Algorithm for Generating Filters and Filter Size

The BF algorithm passes one element through a hash function and generates multiple hash values. This computation is applied to all the elements. A filter is generated by replacing 0 with 1 at the bit positions specified by all the hash values in a bit array, initialized with 0, of an arbitrary size. The algorithm for generating a PF and an AF in a case where each filter is an *m*-bit array, the number of elements is *n*, and the number of hash values obtained is *k*, is as follows (see Fig. 2).

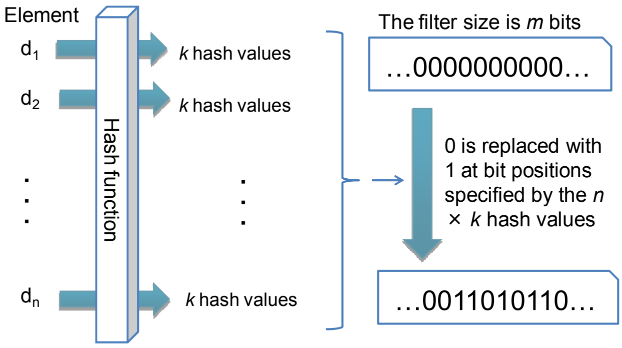

Figure 2. Example of generating a PF and an AF using the BF algorithm.

Step 1: The *m*-bit array is initialized with 0.

Step 2: The character string making up element, d_i, is multiplied with an arbitrary numerical value associated with each alphanumeric in the character string, and again multiplied with the character sequence information. The results for all the characters are added together, and this is converted into a numerical value, $X(d_i)$. For example, if d_i=[gender: 0], then the numerical value are associated with each character in advance, as g=16, e=14, n=23, d=13, r=17, :=36, 0=0. This is multiplied by the character sequence information: g=1, e=2, n=3, d=4, e=5, r=6, :=7, and 0=8. The result is as follows:

$X(d_i)=16\times1+14\times2+23\times3+13\times4+14\times5+17\times6+36\times7+0\times8 = 589.$

Step 3: To calculate *k* hash values from $X(d_i)$, $X(d_i)$ is multiplied by *k* different constants, α_1, ~, α_k, and *k* $X(d_i)_1= X(d_i)\times\alpha_1$, ~ , $X(d_i)_k= X(d_i)\times\alpha_k$ is obtained.

Step 4: $X(d_i)_1$, ~, $X(d_i)_k$ are input to the following hash function, H, to produce *k* hash values, $h(d_i)_1$, ~, $h(d_i)_k$.

$h(d_i)_k = H(X(d_i)_k) = (X(d_i)_k \bmod C) \bmod m$

where *mod* is an operator to obtain the remainder of the preceding value divided by constant, C, or constant, *m*. *m* is the filter's bit length. After the two *mod* operations, this bit length becomes smaller or equal to the bit array length of the defined filter.

Step5: Replace 0 with 1 of the *m*-bit array at bit positions specified by hash values $h(d_i)_1$, ~, $h(d_i)_k$ obtained in Step4.

Step6: Repeat Steps 2 to 5 for the number of elements, *n*.

High bit efficiency of the BF algorithm is achieved by tolerating f*alse positives* [10]. A *false positive* means incorrectly identifying the presence of an element not in the relevant filter, when a match between the PF and the AF is checked. For example, some of the *k* hash values obtained from element, d_i, and those obtained from element, d_j, in Step 4 can be the same sometimes. In such a case, the bit positions specified by the hash value obtained from element, d_j, have already been specified by the hash value obtained from element, d_i, and have been replaced with 1. In other words, these bits are discrimination information encompassing both elements, d_i and d_j. Therefore, in checking a match between the filters, d_i and d_j are not accurately distinguishable. Let *m* be the size of the BF, *n* the number of elements, and *k* the number of hash values obtained by applying the hash function, then the probability at which a *false positive* occurs can be calculated by

$$P = \left(1-\left(1-\frac{1}{m}\right)^{kn}\right)^{k} \approx \left(1-e^{-kn/m}\right)^{k} \qquad (1)$$

Eq. (1) indicates that, if *m* and *n* are fixed, there is a *k* that minimizes this probability. If *false positives* occur in the proposed ad hoc advertisement delivery network, the number of relay nodes increases. Therefore, we have set *m*=150, *n* = 15, and *k* = 7 to keep the *false positive* occurrence probability to 1% or lower. The number of elements, *n*, has been determined based on a questionnaire survey conducted with multiple subjects.

C. Advertisement Suitability Test

The advertising node that was the first to receive an advertisement acquisition message (AAM) from the user must check a match between the user preference information in the AAM and the advertisement information held by each node, and determine the nodes that hold advertisements suitable for the user. A node that has received an AAM from another node must determine whether it should send an advertisement to the user or simply relay the AAM to the next node. With the BF, information is contained at bit positions of a bit array. Therefore, whether information is present or not can be determined by checking whether the value at the relevant bit position is 0 or 1. In other words, if the value is 1 at all bit positions specified by the *k* hash values computed from a given element, that element is valid. On the other hand, if the value at any specified bit position is 0, that element is invalid. The steps for this advertisement suitability test are as follows:

Step 1: A bit *AND* operation is performed on the PF and the AF to produce a Result Filter (RF).

 ISBN: 978-1-61208-210-3

Step 2: If the RF and the AF are identical, the element concerned is determined to be valid. If not, invalid.

IV. ROUTING BASED ON AREA DIVISION

Since advertising nodes are assumed to be installed in shops, they will be at fixed places for a relatively long time. In such a case, a proactive protocol, for which the routing table is predetermined, is an efficient protocol for use as the basic routing protocol. However, if the source node is to search for nodes holding advertisements suitable for the specific user based on a routing table designed for point-to-point connections, it must send many unicast packets to all the target nodes. For example, in a simple node configuration in which the radio from a node can reach only its adjacent nodes as shown in Fig. 3, the routes from node 1 to advertisement holding nodes 3, 6, 8, 9, 10 and 15 are as shown in Table I. Nodes 2, 5 and 7 only relay an AAM, twice, twice and once, respectively. Since the relayed AAM has nothing to do with the delivery of their own advertisements, the AAM traffic is invalid traffic for these nodes. It is desirable that such an AAM do not come to these nodes. Nodes 6 and 10 deliver their own advertisements and also relay an AAM separately. It is desirable that they can handle these in one access attempt. For example, if the routing is such that the AAM is passed in the sequence of nodes 1→2→3→8→7→6→9→10→15, the nodes that only relay an AAM are reduced to only nodes 2 and 7, thus reducing the overall traffic load on nodes and the network.

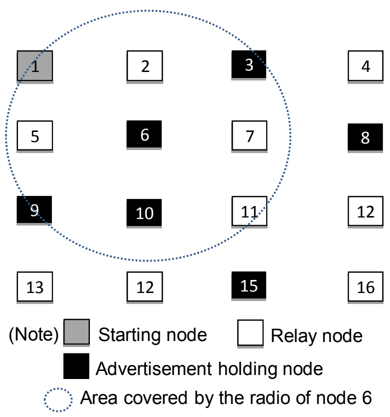

Figure 3. Node configuration example.

TABLE I. ROUTING EXAMPLE USED WHEN THE STARTING NODE, NODE 1, PASSES AN AAM TO ADVERTISEMENT HOLDING NODES 3, 6, 8, 9, 10 AND 15

Node number / UC number	1	2	3	5	6	7	8	9	10	15
UC1	S	R	H							
UC2	S	R				R	H			
UC3	S				H					
UC4	S			R				H		
UC5	S			R					H	
UC6	S				R				R	H

(Note)UC: Unicast, S: Starting node, H: Advertisement holding node, R: Relay node

The control of the relay routing to divided areas is based on an existing proactive protocol but is overlaid on it as shown in Fig. 4. In the upper layer, the area with shops is divided either vertically or horizontally to make up multiple long, thin sub-areas. A set of advertisement holding nodes belonging to the same sub-area are selected, and an AAM is passed from one end of a sub-area if the sub-area number is odd, and from the other end of a sub-area if the sub-area number is even. For example, if the area is divided horizontally, an AAM is passed from the leftmost node in a sub-area whose sub-area number is odd, and from the rightmost node in a sub-area whose sub-area number is even. In the lower layer, an AAM is passed in the sequence determined in the upper layer. If the current node cannot reach the next node in one hop, an alternate route is searched for and used to pass the AAM. By determining the routing this way, an AAM can be passed to nodes in the area in a unicursal line. This is an efficient routing because it reduces the number of nodes that only relay the AAM. Figure 5 shows this routing method for a case where an area is divided into q areas vertically.

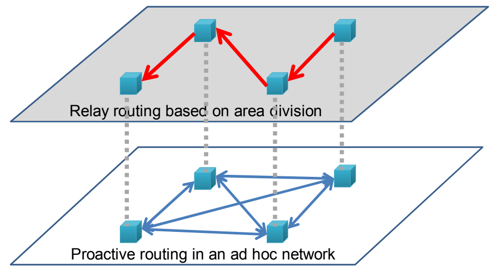

Figure 4. Two-layered routing control.

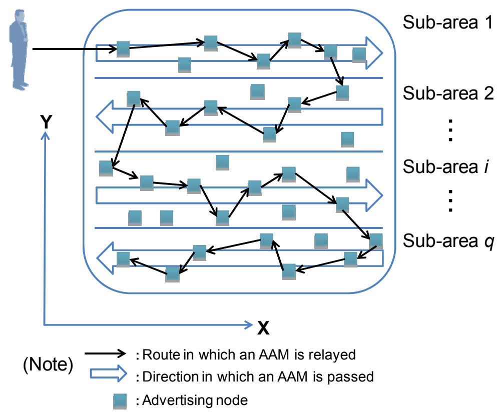

Figure 5. Example of the relay routing based on area division.

The detail routing control is performed as follows. A given area can be divided vertically, horizontally or in other division patterns depending on the layout of shops and users' locations. In the following, we assume that the area is divided vertically into q sub-areas as shown in Fig. 5, and that the starting point is at the top left. Additionally, we assume that each node has the following control data, RD:

RD={node identifier (node_id), IP address (ip_address), location coordinates (location_xy), AF, division pattern identifier (div_id), sub-area number (subarea_no)}

Sub-area number is determined as follows:

 ISBN: 978-1-61208-210-3

$X_s+(q-1) \times w < subarea\_no(q) < X_s+q \times w$, where $(W/w) > q \geqq 1$ and W is the width of the area, X_s is the X-axis coordinate of the starting point, and w is the width of a sub-area.

Step 1: The node that has received an AAM, node N_A, checks a match between the AF in its RD and the PF in the AAM in accordance with the test criteria described in Section III.*C*, and generate a list of nodes that hold suitable advertisements, nodelist NL_A. Note that NL_A and RD share the same attributes.

Step 2: Node, N_A, determines the user location based on its own position, and determines the division pattern identifier. It searches the NL_A for nodes that have this identifier. The nodes found are sorted in the sequence of the sub-area number.

Step 3: Sub-areas are classified into two groups depending on whether the sub-area number is odd or even: $i_o=\{2r-1\}$ and $i_e=\{2r\}$ $(q/2>r\geqq 1)$. It is assumed that r=1 for node, N_A, and the node belongs to i_o.

Step 4: A routing node list RNL is generated by sorting nodes in the sub-area in i_o with r=1 in the order of closeness to node N_A. Note that RNL is an ordered array of node identifiers.

Step 5: Conversely, nodes in the sub-area in i_e with r=1 are sorted in the order of distance to node N_A, and added to the RNL.

Step 6: Make r=r+1. Steps 3 through 5 are repeated for the number of sub-areas belonging to the same division pattern.

Step 7: The completed RNL is put in an AAM, and sent to the next node via the lower layer.

V. Development Of A Simulator And The Evaluation Results

A. Development of a Simulator

To evaluate the methods proposed in Sections III and IV, we specified the size of the target area, developed 5 different node layout lists showing different layouts of randomly placed advertising nodes, and also developed a simulator shown in Fig. 6, which takes the above data as inputs, and outputs suggested routes. We considered 16 types of occupation and 24 types of hobby for the main elements in the AF, which specify advertisement information held in nodes. By combining these with gender, we created 20 AFs and allocated each of them to a node randomly. We also created a PF, which contains one set of elements that indicate the user preference. Only one division pattern shown in Fig. 5 was used. We also developed a unicast simulation program so that we can compare the routing results of the relay routing based on area division with those obtained by using unicast for acquiring advertisement information. A relay node counting program was developed to collect data on the number of relay nodes in the results of both the proposed method and the unicast method. We also developed a relay routing drawing program in order to make it possible to understand different routings visually.

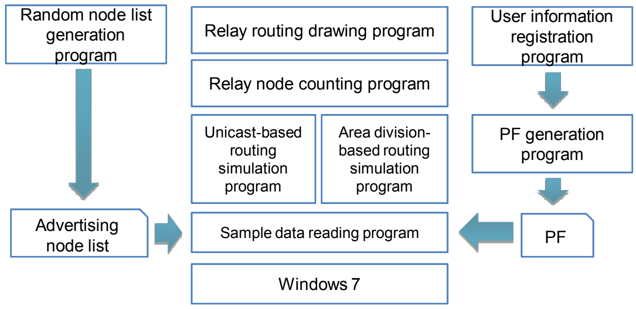

Figure 6. Simulator software configuration.

Figure 7 shows the relay routing in a case where the area with shops measures 800 m × 800 m, the number of advertising nodes is 200, the distance that can be reached by the ratio from each node is 200 m and the area is divided in 5 sub-areas. The number of valid advertising nodes is 66. The number of nodes that relayed AAMs is 67, of which 2 are relay nodes. Nodes are represented by either squares or circles in the figure. Squares indicate nodes that hold advertisements suitable for the user. The selected routes are shown in solid lines. The distance between N:163 and N:80 and that between N:146 and N:53 are longer that the distance that can be reached by the radio waves of these nodes. Therefore, N:194 and N:63 serve as relaying nodes for these pairs of nodes respectively. The new alternate routes are N:163-N:194-N:80 and N:146-N:63-N:53 respectively.

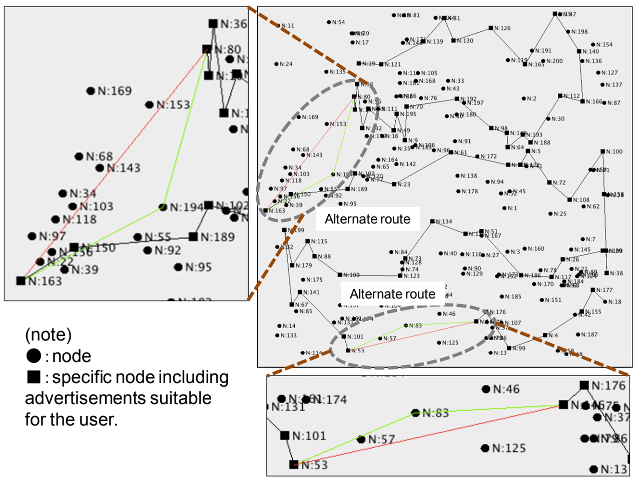

Figure 7. Routes selected for the relay routing based on area division. (Number of sub-areas: 5; number of advertisement holding nodes: 66; total number of nodes that relayed AAMs: 67, number of pure relay nodes: 2, and number of node layout lists: 1)

B. Number of Sub-areas and Number of Relay Nodes

In the proposed routing, the number of sub-areas greatly affects how many node become relay nodes. The relationship between the two as examined with the 5 created node layout lists (nodelists 1 to 5) is shown in Fig. 8. The assumptions used in this examination are the same as those used in Section V.*A*. Figure 8 shows that the number of relay nodes

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is minimal when the number of sub-areas is 5. The reason is that, when the number of sub-areas is smaller or larger than this figure, the distances between advertisement holding nodes are beyond the distance that can be reached by the radio waves from nodes, thus increasing the number of cases where alternate routes with relay nodes must be used to pass AAMs from one advertisement holding node to another.

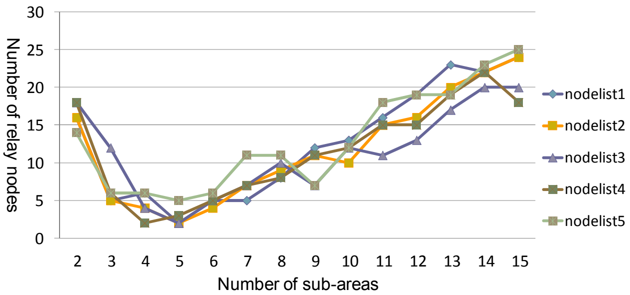

Figure 8. Relationship between the number of sub-areas and the number of relay nodes.

C. Comparison with a Unicast-Based Advertisement Information Acquisition in Terms of the Number of Relay Nodes

The proposed method (method *p*) was compared with the method of unicasting AAMs (method *u*) in terms of the number of relay nodes. The size of the area, the number of advertising nodes, the distance reached by the radio waves from nodes, and the number of valid advertising nodes were the same for the both methods. The computation result for method *u* is shown in Fig. 9. In this method, the advertising node closest to the user sends AAMs to all the nodes that hold advertisements that are considered to be suitable for the user. Therefore, even though the number of advertisement holding nodes was 66 as in the case of method *p*, the number of relay nodes jumped up to 258.

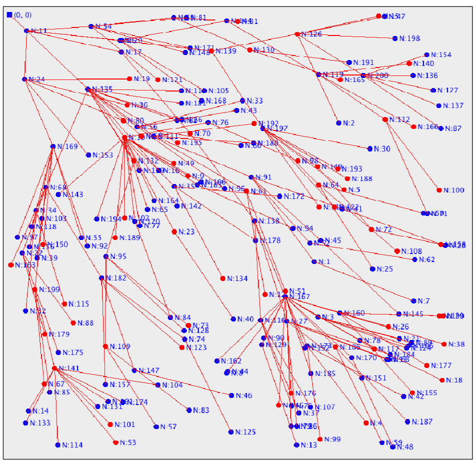

Figure 9. Relay routing based on unicast-type advertisement information acquisition.
(Number of advertisement holding nodes: 66; total number of relay nodes: 258; and the number of node layout lists: 1)

Figure 10 shows comparison of methods *p* and *u* in terms of the number of relay nodes. For method *u*, all the advertising nodes that have relayed an AAM sent by the advertising node closest to the user before the AAM reaches a node holding an advertisement suitable for the user are counted as relay nodes. Such nodes were added together for all the advertisement holding nodes. For method *p*, the number of sub-areas was 5, and 5 advertising node lists were used. A total of 10 simulations were performed for methods *u* and *p*. The route through which an advertisement message is sent from an advertisement holding node to the user is assumed to be the same for methods *u* and *p*. In Fig. 10, the results for method *u* are designated by *u* while those for method *p* are designated by *p*, followed by the list number of the advertising node list used. Figure 10 shows that the number of relay nodes for method *p* is much smaller than for method *u*. The percentage of this reduction ranged from 68.2% to 74.5% with the average being 71.9%.

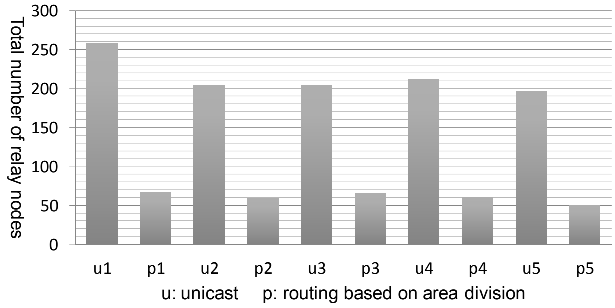

Figure 10. Comparison with a unicast-type advertisement information acquisition in terms of the number of relay nodes.

VI. RELATED WORKS

Typical overlay-based multicasting protocols that use the proactive routing of ad hoc networks include AMRoute (Ad hoc Multicast Routing protocol) [11], PAST-DM (Progressively Adaptive Subtree in Dynamic Mesh) [12] and ALMA (Application Layer Multicast Algorithm) [13]. In these protocols, each member node forms a mesh-based virtual topology. Information delivery is achieved using a multicast tree in the case of AMRoute, and a source-based tree in the cases of PAST-DM and ALMA. ALMA takes a receiver-driven approach to improve the performance of PAST-DM.

Our proposed method also relies on a source-based tree. It differs from PAST-DM in the following aspects. Since PAST-DM's meshed-based virtual topology assumes node mobility, the link states are updated periodically. The source-based tree used for information delivery is dynamically generated by the source-based steiner tree algorithm from this virtual mesh. Therefore, control packets for obtaining the latest routing information are periodically flooded, which results in an increase in network traffic. The parent node, which is the branching point of the tree, manages the participation and withdrawal of child nodes, copies the packets as many times as there are child nodes, and sends the copied packets.

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In contrast, in our proposed relay routing method based on area division, the nodes that make up the ad hoc network are shops at fixed locations. Therefore, in setting up the network, it is possible to build a virtual topology as an unbranched source-based tree in which nodes are connected in the sequence of physical distances between nodes for each area division pattern. This also reduces the number of control packets. In addition, the source-based relay routing tree for the transmission of advertisement information acquisition messages over the network is reconfigured as an unbranched relay routing tree by selecting, from this virtual topology at the time when the advertisement information acquisition messages is received from the user, only those nodes that hold advertisements suitable for the preferences of the user. The participation or withdrawal of a delivery member is updated as part of the operations and maintenance system data when the relevant node is physically included in or disconnected from the advertising delivery ad hoc network. The routing at the time of node failures is left to the lower layers as is the case with other methods.

VII. Conclusions And Future Issues

This paper has proposed a locality-oriented ad hoc advertisement delivery network. It has described the filter structure and the algorithm used to determine whether an advertisement is suitable for a specific user based on the Bloom Filter algorithm. In addition, it has proposed a relay routing method based on area division. This method can reduce the number of nodes that purely relay advertisement information acquisition messages in an ad hoc network. This method has been compared with a unicast-type advertisement information acquisition using simulation, and it was found that the proposed method uses 70% fewer relay nodes than the unicast-type method.

In the future, it will be necessary to examine cases that take into consideration node layouts that reflect actual cases, different area division patterns, the impacts of users' movements and those of buildings on reachability of radio waves. In addition, it is necessary to study in detail the protocol that enables the proposed relay routing algorithm based on area division, and to use general-purpose network simulators, such as Opnet [14] and NS-2 [15], to evaluate the delay up to the final node when the network's background traffic is taken into consideration, and the effects of node failures. It is also necessary to investigate the standard used for the optimization of the relay routing tree based on area division. The quantitative difference in performance between the proposed method and the existing ALM (Application Layer Multicast) needs to be found out through these studies.

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Evaluation of Biomedical Signals Data from Moviegoers

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***Abstract*—Moviemakers must be able to estimate moviegoer's level of engagement while watching the movie. Thus far, however, most studies have focused on the story itself from the viewpoints of subjective reviewers. In this study, we tried to estimate the engagement of moviegoers objectively by measuring their physiological signals. The physiological signals include electroencephalogram and photoplethysmogram. However, it is difficult to measure biomedical signals compared to subjective review questions. Therefore, many researchers want to share the biomedical signal data. For this reason, it is important to evaluate the reliability of the biomedical signal data. In this research, we invented a new formula for engagement and evaluated the reliability of the biomedical signals measured from moviegoers as participants. The reliability of our data is verified by its consistency between electroencephalogram and photoplethysmogram as well as by comparison to subjective review results.**

Keywords- biomedical signals; moviegoers; reference data; reliability; consistency

I. INTRODUCTION

For the movie industry to be successful, movies must fully engage moviegoers. The engagement appears to emerge from the interaction between message structure and content [1]. Although the moviegoer engagement may have observable behavioral correlates such as the direction of gaze, it is not itself directly observable by others. As a result, judgments about whether, or how much, a movie succeeds in engaging the moviegoer are typically inferred by indirect or *post hoc* measures such as subjective ratings [2]. Standard marketing techniques employed so far have involved the use of interviews and the compilation of questionnaires for the subjects after viewing the movie. Nowadays, however, the focusing of attention can be monitored by measuring associated changes in brain electrical activity with the electroencephalogram (EEG). Thus, in principle, EEG measures have the potential to provide a more direct and objective method for gauging the intensity and nature of moviegoer engagement [3].

Because the EEG is mainly due to the activity generated on the cortical structures of the brain, it is almost impossible to precisely infer the moviegoer's emotions being processed in the deep brain [4]. Hence, it is practical to infer the internal emotional state of the moviegoer by using indirect signs, such as the activity of the sweat glands on the hands and/or the variation of the heart rate [5]. Therefore, when we evaluate the reliability of the biomedical signals data, the biomedical signals of the autonomic nervous system as well as the EEG of the central nervous system are considered together. If we measure and evaluate the EEG alone, it is a one-dimensional assessment of the data because it focuses on the replication of a single observation. According to National Institute of Standards and Technology (NIST), higher-dimensional assessments, yielding correspondingly higher levels of confidence, may be constructed using correlations with other measurements and theoretical models. In the NIST approach, multiple independent observations of related properties are used together to assess the reliability of any one of them. Since each property represents a different measurement perspective, a higher level of confidence may be ascribed to these data collectively, owing to the consistency of the observations across the multiple properties, than could be ascribed to any one of the properties individually. The dataset is viewed through its relations to other data, particularly through trends, correlations, and known material property relations. The central focus of this evaluation is on consistency [6].

In this study, we analyzed the brain activity as well as the autonomic nervous activity of the moviegoer while watching the movie. To measure both the brain activity and the emotional engagement of the 38 healthy participants, we used simultaneous EEG and photoplethysmogram (PPG) measurements during the entire experiment. We hope to link significant variations of EEG and PPG measurements with the subject's review results. Previous studies have shown that the moviegoer is in an engaged state when pleasure accompanies the moviegoer's concentration on the movie. As an index for concentration, the power of the 'low beta' frequency band, 13 to 20 Hz, of EEG is increased while that of the 'theta' frequency band, 4 to 8 Hz, is decreased [7]. By the Wendy Heller model [8], when the moviegoer feels pleasure, the left frontal cortex is more activated compared to that of the right, i.e., the power of the 'alpha' band, 8 to 13 Hz, of the EEG on the right side of the frontal cortex is larger than that on the left side of the frontal cortex. This study examines whether changes in the biomedical signals of the peripheral nervous system as well as the spectral composition and regional cortical distribution of the EEG might be systematically related to the degree of a moviegoer's engagement in the movie. In this study, we defined the engagement index which is the sum of the concentration index and the pleasure index.

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II. METHOD

A. Experimental Design

Thirty-eight healthy volunteers (range = 18 to 38 years old, mean age 23.3 ± 4.7 years; 14 women) living in Orlando, Florida in the USA were recruited for this study. When the participants arrived at the University of Central Florida Center for Emerging Media (UCF CEM), they were fully informed of the purpose of the experiment and its procedure and subscribed on the consent form, which was approved by the institutional review board (IRB) of UCF. Next, they were guided to an audio-video room (AV room) for the experiment. The AV room was an electrically-shielded, dimly-lit room. As an AV system, a Sony 1,000 Watt, 5.1 Surround Sound, Blue Ray Home Theater System (BDVE580) was used.

The procedure of the experiment consisted of two parts. The first part was to measure biomedical signals from participants during watching the 112-minute American film, *Iron Man.* During this first part, subjects were requested to pay attention to the movie and not move their fingers, etc., if possible. The second part, after watching the movie, was to evaluate how the participant felt while watching the movie. In this second part, subjects were asked to recall when and why they felt the most pleasure, most anger, most engaged, etc., in the film. The experiments were carried out three times a day: the first session was from 8 am to 12 pm, the second session was from 1 to 5 pm, and the last session was from 6 to 10 pm. In each session, three or four participants attended simultaneously (refer to Fig. 1).

After the participants sat down on the comfortable chairs in the AV room, the electrodes of the biomedical signals were attached to the participants. To measure two channels of the EEG, the AgCl electrodes were attached at Fp1 and Fp2 for active signals, at A1 and A2 linked for reference, and at Fz for a ground according to the international 10-20 electrode placement system. EEG conduction cream was applied to attach the electrodes and kept the impedance below 5 kΩ. To measure one channel of the PPG, its sensor was attached on the index finger. A strap was used to attach the PPG sensor. The conduction gel was used to enhance the conduction. After attachment of the electrodes, the participants took a 10-minute baseline state. Then, the main experiment of measuring biomedical signals was begun. The biomedical signals, two channels of EEG and one channel of PPG, were recorded for each participant. Therefore, 12 channels of biomedical signals from four participants were recorded during 112 minutes by means of MP150 and Acq*Knowledge* software version 4.2 (Biopac, USA, [9]).

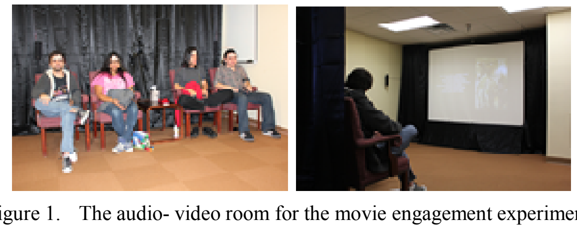

Figure 1. The audio- video room for the movie engagement experiment.

To minimize any contributions from offset effects and any uncertainty about the temporal alignment of the movie presentation with the biomedical signals' time series, the first 1 minute of each signal was eliminated. After that, the starting points of each of the 38 signals were aligned for the EEG and for the PPG, respectively. Finally, the power spectrum was analyzed over equal length to the shortest length of 38 signals for the EEG and for the PPG, respectively.

B. Recordings for Central Nervous System

Raw EEG traces were first band pass filtered (high pass = 0.5 Hz; low pass = 30 Hz). We collected the EEG activity to a personal computer at a sampling rate of 1,000 Hz. The EEG traces were then segmented with 30-second windows to remove the segments containing severe noises due to eye movements, blinks, and muscular artifacts. The criteria of rejection was larger than + 80 μV or less than - 80 μV. Fast Fourier transforms (FFT) were then computed on 50%-overlapped groups of 512 sample (0.5 second) Hanning windows for all artifact-free data segments, providing estimates of spectral power with 0.125 Hz frequency resolution. Then, the FFT was applied to obtain the power spectral density (PSD) for each segment of a good signal-to-noise ratio. The PSD for a 30-second window moving with a 10-second interval was calculated for the entire 112 min.

C. Recordings for Autonomic Nervous System

Autonomic activity, the variations of the peak intervals of PPG, was recorded with an MP150 system and Acquisition software version 4 (Biopac, USA) with a sampling rate of 1,000 Hz. The PPG sensor was attached to the palmar side of the second finger of the participant's non dominant hand by means of a velcro fastener. Before applying the sensors, the subjects' skin was cleaned. The PPG signals were continuously acquired for the entire duration of the movie, and its PSD was calculated. In this way, we obtained a signal in the frequency domain for the biomedical signals from moviegoers. In particular, the whole interval was spanned with a series of time windows of 5 min each.

Spectral components were identified and then assigned, on the basis of their frequency, to one of two bands: Low Frequency (LF), 0.04 to 0.15 Hz, or High Frequency (HF), 0.15 to 0.4 Hz. These components were obtained in absolute values of power (ms^2). The Very Low Frequency (VLF) band, 0.01 to 0.04 Hz, was excluded from the present analysis since it is not of interest for our purpose. Several studies indicate that the LF band corresponds to baroflex control of the heart rate and reflects mixed sympathetic and parasympathetic modulation of Heart Rate Variability (HRV); instead, the HF band corresponds to the vagally mediated modulation of HRV associated with respiration. The ratio LF/HF was used as the index of the balance between the sympathetic and vagal activity [10]. For emotion, previous study showed that the ratio MF/(LF+HF) reflects positive emotion while the ratio LF/HF reflects negative emotion, where the MF is a Middle Frequency band of 0.08 to 0.15 Hz [11].

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III. RESULTS AND DISCUSSIONS

A subjective review result of when and why the participant was most engaged is shown in Table 1 for five representative participants among 38 participants, and the corresponding scenes are shown in Fig. 2. In this study, we invented a new formula evaluating the participant's engagement as follows:

$$Z \equiv aX + bY \qquad (1)$$

where the Z : index of engagement, X : index of concentration, Y : index of pleasure, a and b are the weighting factors. In this research, the a and b are set to 1.

$$X \equiv Fp_{[1+2]}(\beta_L/\theta) \equiv \frac{Fp_1(\beta_L)+Fp_2(\beta_L)}{Fp_1(\theta)+Fp_2(\theta)}, \qquad (2)$$

where,
$Fp_1(\beta_L)$: EEG power of low beta band, 13 to 20 Hz, at Fp_1
$Fp_2(\beta_L)$: EEG power of low beta band, 13 to 20 Hz, at Fp_2
$Fp_1(\theta)$: EEG power of the theta band, 4 to 8 Hz, at Fp_1
$Fp_2(\theta)$: EEG power of the theta band, 4 to 8 Hz, at Fp_2

$$Y(central) \equiv nFp_{[2-1]}(\alpha) \equiv \frac{Fp_2(\alpha)-Fp_1(\alpha)}{Fp_2(\alpha)+Fp_1(\alpha)}, \qquad (3)$$

where,
$Fp_1(\alpha)$: EEG power of the alpha band, 8 to 13 Hz, at Fp_1
$Fp_2(\alpha)$: EEG power of the alpha band, 8 to 13 Hz, at Fp_2

$$Y(pheriperal) = \frac{MF}{(LF+HF)}, \qquad (4)$$

where,
MF : PPG power of 0.08 to 0.15 Hz
LF : PPG power of 0.04 to 0.08 Hz
HF : PPG power of 0.15 to 0.4 Hz

By using from (1) to (4), the concentration from EEG and the pleasure from EEG and PPG were calculated, averaged over 38 participants, and shown in Fig. 3. Between 70 and 75 minutes, the concentration index of EEG as shown in the upper part, the pleasure index of EEG as shown in the upper part, the pleasure index of EEG as shown in the middle part, and the pleasure index of PPG as shown in the lower part are relatively very high. These peaks are shown in red rectangular boxes in Fig. 3. Moreover, most of subjective review results in Table 1 also showed the strongest engagement during this time interval. The EEG and PPG measured from 38 participants showed consistency from the viewpoint of engagement. Therefore, the reliability of our dataset as well as the new formula for engagement is verified. To represent the participant's emotion precisely, it is necessary to measure the biomedical signals from the peripheral nervous system as well as from the central nervous system. Our results also support the previous hypothesis that if the participant is in the engagement state while watching the movie, the pleasure accompanies the concentration on the movie.

TABLE I. RESULTS OF REVIEW QUESTIONAIRE FOR *IRON MAN*

Partici pants	**Time period of maximum engagement**	**Subject evaluation:** ***(The reason why the most engaged)***	**Physiological signals**
1	72 m 07 s ~ 81 m 01 s	This is the scene where the newly finished/painted Mark 2 suit is first being used. Tony uses it to destroy the terrorist village and save innocent people.	In Fig. 3 between 70 and 75 minutes, the concentration from EEG (upper part) and the pleasure from EEG (middle part) and from PPG (lower part) averaged over 38 participants are relatively very high.
2	72 m 50 s ~ 72 m 51 s	Iron man suit with new color scheme.	
3	74 m 13 s ~ 80 m 48 s	Iron man was cool to see fighting.	
4	73 m 00 s ~ 78 m 00 s	This was an action scene.	
5	74 m 14 s ~ 79 m 12 s	It makes me happy that Tony perfected his project and he can help others and fly anywhere he likes.	

Figure 2. Corresponding scenes of *Iron Man*, selected from each time intervals in Table 1, when the participants were most strongly engaged.

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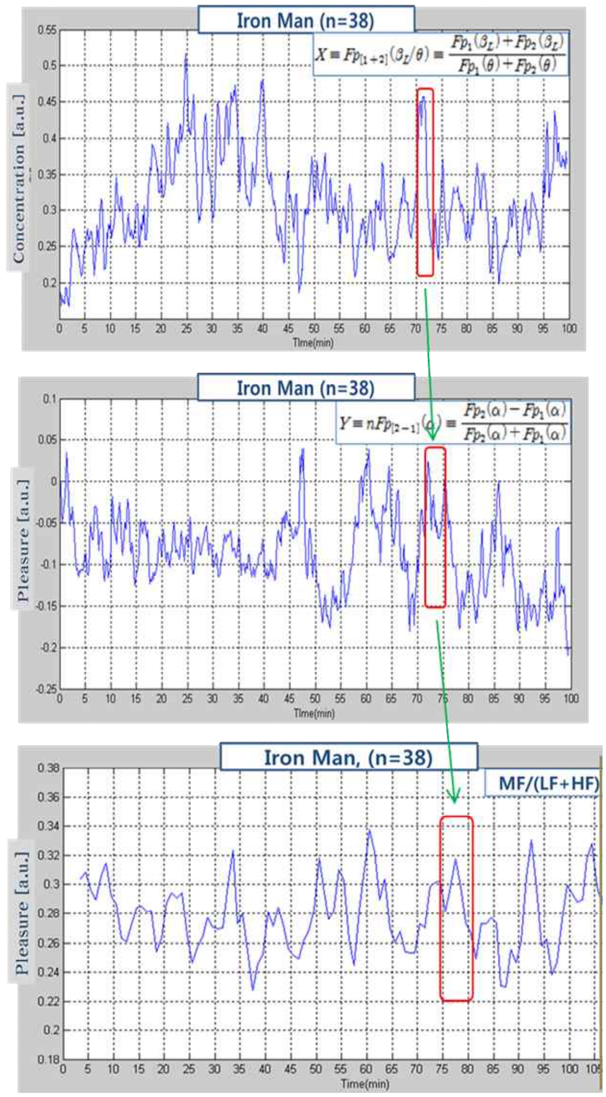

Figure 3. Change of participant's concentration (upper) evaluated from EEG, pleasure evaluated from EEG (middle) and from PPG (lower).

IV. CONCLUSION

For the same time interval, the concentration from EEG and the pleasure from EEG and PPG calculated from the new formula were relatively very high. This show that not only the pleasures calculated from the EEG and the PPG separately are consist but also it accompanies the concentration simultaneously. Moreover, most of subjective review results also showed the strongest engagement during this time interval. Therefore, the validity of our dataset as well as our formula are verified. Our results also support the previous hypothesis that if the participant is engaged in watching the movie, pleasure accompanies this concentration on the movie.

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Bluetooth Proxying and Communication with 802.11 Wireless

An Android solution to an African problem

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***Abstract*—Cellular technology has drastically simplified the way in which we communicate with one another. People are far more mobile than before, and yet just as accessible. Cellular technology plays a vital role in connecting remote areas in Africa to one another, and even in and amongst extreme levels of poverty, this technology is still employed. The major problem with cellular networks is that they are expensive to setup, and expensive to maintain, which results in consumers (often those who are living below the breadline) having to pay exorbitant rates for voice communication which often takes place in the bounds of a local community or city. This paper proposes the design and implementation of a free community telephone network in rural areas in South Africa, using low cost, yet efficient technology to fulfill the role of cellular networks. This paper shows how a single high powered Android device (*Blue Bridge*) can combine the Bluetooth and 802.11 wireless protocols using a lightweight and non-broadcasting based protocol (*Linkage*) to inform nodes on either network of one another. This paper also proposes the expansion of 802.11 wireless networks, and thus remote connectivity between *Blue Bridge* nodes through SSID and channel matching.**

Keywords-Bluetooth bridging; Bluetooth proxying; 802.11 wireless expansion; Mesh; Community telephone networks

I. INTRODUCTION

Bluetooth is a lightweight, short distance wireless protocol which was introduced by Ericsson in 1994 [1]. The Bluetooth protocol has slowly but surely been replaced by 802.11 wireless [23] on cell phones, due to its bandwidth and scalability limitations. The Bluetooth Special Interest Group (SIG) has introduced a number of improved Bluetooth versions since its inception in 1994. According to Wi-fi Planet [2] it is however unlikely that upgraded Bluetooth versions will replace 802.11 due to the current widespread use of 802.11 in existing handsets, and the significant difference in the available bandwidth between the two protocols.

With that said Bluetooth V3.0 High Speed has vastly improved data rates and according to Gsmarena [3], this new version of Bluetooth is more suited to establishing quick hassle free connections between cell phones and computers for file transfer. Gsmarena suggests that 802.11 wireless is a more suitable option for permanent and reliable network connectivity [3].

There is an ongoing debate as to which protocol should be the primary protocol for data transfer on cell phones, and although the common outcome is that 802.11 wireless is far superior to Bluetooth, this paper aims to demonstrate the importance of the Bluetooth protocol and the role it plays in impoverished communities in South Africa and the African continent as a whole.

It is no secret that poverty is widespread throughout the African continent, with the average income available for the purchase of normal to high end 802.11 wireless enabled phones dwindling in comparison to that of first world nations. As such, the vast majority of cell phones in use in South Africa do not contain 802.11 wireless technology, leaving the Bluetooth protocol as the primary option for data transfer between cell phones.

Although Bluetooth is the most widely spread protocol on cell phones in South Africa, 802.11 wireless is by no means worthless. Rural communities in South Africa are typically separated by large distances which makes the interconnection of these communities an ideal platform for the implementation of low cost 802.11 wireless technology. As mentioned above, Bluetooth is more suited toward creating an effortless wireless link between computers and cell phones for the purposes of data transfer, and 802.11 wireless is more suited to the establishment of reliable more scalable networks. As such 802.11 wireless technology is a fantastic alternative, both in terms of the cost of implementation and the scalability when compared to the already widely adopted radio based cellular networks.

The obvious challenge in this instance is the development and successful implementation of a scalable platform which combines the Bluetooth protocol and its more powerful counterpart, 802.11 wireless.

The infrastructure and methods of implementation presented in this paper are from a theoretical perspective, and as such there are no results. We provide a number of different methods of implementation and highlight existing and possible issues as well as means to overcome these constraints.

As such, this paper aims to provide an overview of an application level platform which combines Bluetooth and 802.11 wireless, through Bluetooth Proxying as well as the subsequent expansion of 802.11 wireless networks through

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SSID and channel matching. We chose to use Android as the proof of concept platform, even though Java Mobile is the most widely spread mobile platform suited to mobile application development in South Africa. The reason for Android being the preferred development platform is the associated powerful hardware which is required for the purposes of this research. The Android platform is also more suited to wireless hotspot configuration and the implementation of audio compression methods.

Section II provides an overview of the Bluetooth and 802.11 wireless protocols. Section III gives a brief introduction to the Android platform and provides an overview of the Bluetooth and 802.11 wireless protocols on this platform. After the aforementioned background on the protocols and platforms, Section IV introduces the concept of Bluetooth proxying, the proposed infrastructure to bridge Bluetooth and 802.11 wireless on the Android platform. Section V provides a brief overview of 802.11 wireless expansion which is then followed by an overview of the benefits, constraints, and overall feasibility of a proposed large scale implementation, as well as possible future extensions to this paper in Section VI. Section VII concludes this paper.

II. BLUETOOTH AND 802.11 OVERVIEW

A. *Bluetooth Overview*

Bluetooth was initially invented to be a cable replacement technology for mobile devices and desktop computers alike. The Bluetooth protocol was designed with three key features in mind: small chip size; very little power consumption; and low cost. With the successful implementation of the above pre-requisites for the Bluetooth protocol, it was envisioned to become the standard for seamless short range wireless communication between devices [4]. There are three power classes of Bluetooth devices which accomplish various distances and are intended for varying purposes: Class 1, Class 2, and Class 3. Class 1 Bluetooth devices achieve a range of 100m, Class 2 devices achieve a distance of 10m, and Class 3 devices achieve a distance of 1m. The vast majority of Bluetooth enabled devices fall into the Class 2 category, which is ideal for short range wireless communication [5]. Huang and Rudolph [5] suggest that the distances achievable by the various Bluetooth power classes are merely guidelines, and that the actual distances achieved are heavily influenced by surrounding obstacles and other transmissions within the 2.4 GHz frequency band.

Apart from the various power classes of Bluetooth which impose limits on the maximum transmission distance between two devices, another limiting factor which severely constrains the Bluetooth protocol and its suitability for scalable applications is the number of simultaneous connections in Personal Area Networks (PAN). Although Bluetooth was originally intended as a cable replacement for Point to Point connections, it fast became popular due to its ability to create PANs which are otherwise known as ad-hoc networks [6]. PANs enabled multiple devices (up to eight) to communicate with one another through a Master node [7].

Bluetooth Piconets and Scatternets are synonymous with PANs. When there is one Master node and one Slave node a Point to Point connection is established and a Piconet is formed. A Piconet is also formed when there are multiple Slave nodes which are connected to one Master node (Point to Multipoint). In both cases the Slave nodes follow the frequency hopping sequence of the Master node [7].

The obvious limitation with Bluetooth PANs is the maximum of eight active devices in the same Piconet. Scatternets, although not clearly defined by the Bluetooth Special Interest Group (SIG), are formed when multiple Piconets communicate with one another. In Scatternets, a device can be a Master node in one Piconet and Slave node in another Piconet; or a Slave node in both Piconets; but never a Master node in both Piconets [7].

Bluetooth bandwidth is yet another very important consideration where scalability is concerned. According to Huang and Rudolph [5] the theoretical asymmetric data rate achieved between two Bluetooth devices is 723.2 kilobits per second (kbps) and the maximum theoretical symmetric data rate is 433.9 kbps. Asymmetric transmission in this case refers to one Bluetooth device transmitting while the other one receives the transmission. Symmetric transmission occurs when both devices are transmitting and receiving. Sahd [8] found the average asymmetric data rate between a Nokia N95 8GB and Nokia N82 to be 136.17 Kilobytes per second (KBps), which is slightly faster than the theoretical transfer speeds suggested by Huang and Rudolph [5]. Now that we have provided an overview of the Bluetooth protocol and it's constraints, we are able to more efficiently design applications which take all of these constraints into account and make the necessary adjustments. The following sections will motivate why Bluetooth is by no means an outdated protocol, and how it can be used in combination with 802.11 wireless for the implementation of a low cost community telephone network. The next section provides an overview of the 802.11 WLAN protocol.

B. *802.11 WLAN Overview*

According to Gast [9], the two main benefits of wireless networks are mobility and flexibility. With the world in which we live, becoming increasingly more mobile, the need for mobile technologies and the various forms in which they occur (flexibility) also increases. Products based on the 802.11 protocol were initially released in 1997, with the 802.11 consisting of three main layers: The Infrared (IR) layer, and two spread-spectrum radio layers: frequency hopping (FH) and direct sequence (DS).

There are four widely used 802.11 standards: 802.11a, 802.11b, 802.11g, and 802.11n. Each of these standards barring 802.11n (completely new multi-streaming standard) is either an improvement or modification of one of the other standards. Even though these standards are collectively known as the 802.11 standards, they are often referred to as 802.11 wireless.

There are two main frequency bands in which these standards operate: the 2.4 GHz *unregulated* frequency band, and the 5.0 GHz *regulated* frequency band. 802.11a operates in the 5GHz frequency band, and achieves a maximum throughput of 54 Mbps. 802.11b operates in the 2.4 GHz frequency band (same band as Bluetooth) and achieves a maximum throughput of 11 Mbps. 802.11g operates in the 2.4 GHz frequency band and has a maximum throughput of 54 Mbps. 802.11n can operate in the 2.4 GHz or 5.0 GHz frequency bands, or both simultaneously. 802.11n achieves a maximum throughput of 600 Mbps due to the use of wider channels (40 MHz instead of 20 MHz). With that said, 802.11n is backward compatible with 802.11a, 802.11b, and 802.11g, thus making it extremely versatile and by far the best choice for scalable applications which require large amounts of bandwidth. Since the 2.4 GHz frequency band is unregulated, there is a lot more interference which occurs in this band, and as a result the bandwidth measurements vary according to the amount of interference encountered. When the 802.11n standard utilizes the 5.0 GHz frequency band, the number of overlapping channels increases due to the wider channel width of 40 MHz.

One of the common questions asked is whether Bluetooth and 2.4 GHz based 802.11 wireless encounter issues with interference when in close proximity to one another. Luckily both protocols have measures to deal with interference in the unlicensed 2.4 GHz frequency band. In order to deal with interference, Bluetooth employs a frequency hopping scheme, which enables it to transmit each packet on a different frequency. Bluetooth is generally comprised of 79 channels (dependent on country of operation), and the transmission time allowed for each slot is 625µs, thus allowing Bluetooth to achieve 1600 hops per second, which significantly reduces the likelihood of interference. The frequency hopping scheme is determined by the master node in the Piconet. With that said it is clear that Bluetooth employs a very sophisticated interference avoidance model in the unlicensed and often interference riddled 2.4 GHz frequency band.

The 2.4 GHz frequency band (on which 802.11b and 802.11g operate) is comprised of fourteen channels with each channel separated by 5 MHz. The United States only has 11 channels available in the 2.4 GHz frequency band due to policies enforced by the Federal Communications Commission (FCC). 802.11b and 802.11g wireless require a 22 MHz range to modulate the wireless signal, and since each channel in the 2.4 GHz frequency band is separated by 5 MHz, there is a substantial amount of channel overlap [10].

With the large amount of channel overlap in the 2.4 GHz frequency band, there are only three non-overlapping channels: Channel 1; Channel 6; and Channel 11. What this effectively means, is that even though wireless devices (on the 2.4 GHz frequency band) are on different channels, they still interfere with one another apart from the aforementioned channels.

Unlike Bluetooth, 802.11b and 802.11a operate on a fixed channel which makes them a lot more susceptible to interference.

The next section introduces the Android platform and the operation of Bluetooth and 802.11 wireless on this platform.

III. ANDROID

Android is often described as a software stack for mobile devices, and is comprised of an operating system, middleware, and a plethora of applications [12]. Android's architecture is comprised of a hierarchical stack of components, with applications forming the top most layer, and the Linux kernel forming the lowest layer [13]. Figure 1 depicts the Android architecture or component stack:

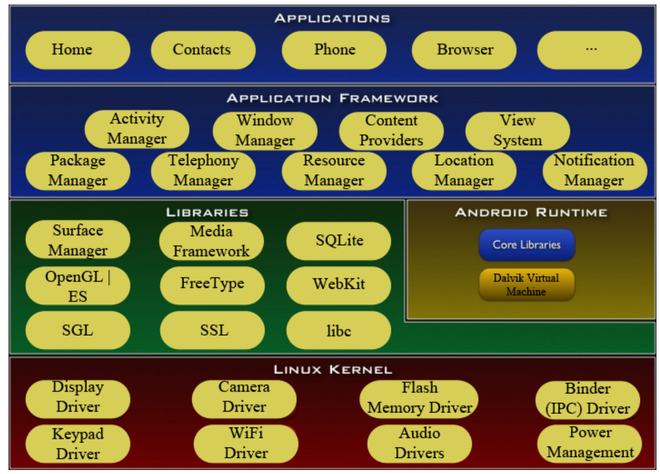

Figure 1. Android component stack

From Figure 1 it can be seen that Android's lowest layer is the Linux kernel upon which all the other layers run. Android Libraries and runtime are situated above and are dependent on the Linux kernel. The Application framework provides the necessary services and systems which applications are dependent upon. Android comes standard with a set of core applications (email, SMS, calendar, etc.) and other applications written in the Java programming language can be installed [12].

One of the most important components of the Android component stack, which is located in the Android Runtime, is the Dalvik Virtual Machine [14]. The Dalvik Virtual Machine is Android's answer to the Java Virtual Machine (JVM), and it enables multiple instances of the Virtual Machine to be run simultaneously and takes advantage of the Linux operating system for process isolation and security [15]. Dalvik Virtual Machine differs from the JVM in that it executes .dex files which are converted from .class and .jar Java files at compile time. The benefit of the .dex files is that they are more compact and efficient than their Java equivalents and this proves to be a very important consideration for devices with limited battery and memory [15].

According to Meier [14], Android belongs to a new wave of mobile operating systems which have been designed for the increasingly more powerful hardware. With the increased power of the hardware of mobile devices, comes an increase in the capability and scalability of services which can be hosted on these devices. Meier [14] describes a number of application services which are crucial in providing developers with the necessary functionality required for

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application development: Activity Manager; Views; Notification Manager; Content Providers; and the Resource Manager. The Activity Manager controls the lifecycle and management of activities; Views are a means of constructing the interfaces for your activities; The Notification Manager provides a means for signaling users with notifications related to the activities described above; Content Providers enable inter application communication through the sharing of data; The Resource Manager supports non-code resources like strings and graphics.

With an introduction to the Android platform, the next section introduces the concept of Bluetooth proxying and describes the proposed infrastructure.

IV. BLUETOOH PROXYING AND INFRASTRUCTURE

Before we look at Bluetooth proxies and how they operate, it is necessary for a definition of proxy servers themselves. Indiana University [16] defines a proxy server (or application level gateway) as a computer that acts as a gateway or intermediary between one network and another. For the purposes of this research and as a general rule of thumb, proxy servers need not be implemented on a computer alone. Proxy servers are generally found at the Network layer (Layer 3) or higher of the Open Systems Interconnection (OSI) model [22], and they provide vital services such as the forwarding of traffic between source and destination, as well as efficiency improvements through information retrieval through proxy cache's [16]. Figure 2 depicts the various layers in the OSI model:

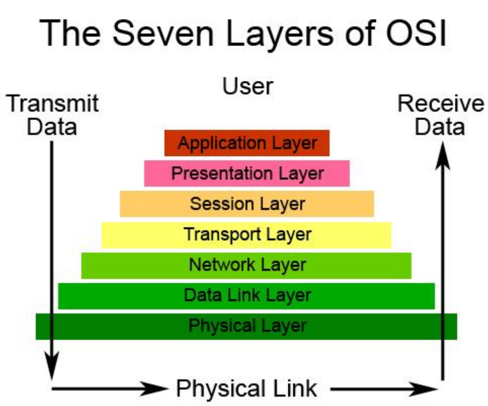

Figure 2. OSI Network Model [17]

Depending on which OSI layer proxy servers operate on, their implementation is somewhat different. Android provides a wide variety of libraries which enable seamless access to lower level resources from layers high up in the OSI model (presentation and application layers). As such, we propose the implementation of an application level proxy which enables the seamless communication between devices on a Bluetooth network and those on an 802.11 wireless network.

A. *Bridging and communication*

Theoretically, it would be possible to bridge the Bluetooth and 802.11 protocols if they were operating on the same channel and if necessary adjustments were made to both protocols to enable them to communicate with one another. Another look at Section 2, Subsection B would show that due to the interference avoidance models of the Bluetooth protocol, it would be highly unlikely that an approach to enable communication between the two protocols would be implemented at OSI layers below the Presentation layer (layer 6).

In order for the two protocols to communicate with one another, they need a means of communication. Since there is no existing method for enabling this communication between Bluetooth and 802.11 wireless, we propose an application level framework called *Blue Bridge*, which essentially intercepts and interprets information from one source and forwards it to another. *Blue Bridge* is built on the Android platform, and is ideally run on a high end Android phone such as the Samsung Galaxy SII [18]. The Samsung Galaxy SII referred to as the "Samsung" from now on is comprised of a 1.2 GHz Cortex-A9 processor; 802.11 a/b/g/n wireless; Bluetooth V3.0+HS; 1 GB RAM and 16 GB internal storage. The Samsung runs V2.3.4 Android (Gingerbread) and is upgradable is V4.x [19]. With high end specifications such as these, the Samsung should be more than capable of intercepting connections on either the Bluetooth or 802.11 interfaces.

The Android platform was chosen as the primary platform for *Blue Bridge* due to its wide scale adoption in high end cell phones (which are necessary for the purposes of this research), and its ability to establish Bluetooth and 802.11 wireless connections at the application level. The Samsung was chosen was the device of choice for *Blue Bridge* over and above conventional wireless routers, due to the Bluetooth and 802.11 wireless interfaces already being present in the device. The Samsung was also chosen due to its size, low power requirements, and the fact that this device could be concealed and kept safe from prying eyes. Conventional 802.11 wireless routers are rarely equipped with Bluetooth interfaces and as such Android enabled cellphones were chosen as a more appropriate platform which tackles the issue at hand.

Blue Bridge creates a Bluetooth PAN and an 802.11 wireless hotspot which enables nodes from either network to connect to the Samsung and essentially proxy communications through the *Blue Bridge* node to one another. For the purposes of simplicity we will refer to the Bluetooth interface as Interface 1, and the 802.11 wireless interface as Interface 2. There are two methods which we propose for the receiving and forwarding of data from one interface to another:

1. Any data received on Interface 1 of the Samsung *Blue Bridge* receives all of the data before forwarding / retransmitting it to the destination device on Interface 2.

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2. Any data received on Interface 1 of the Samsung *Blue Bridge* forwards / retransmits data on the fly from the streams and buffers handling the current transmission.

On a powerful Android device such as the Samsung, Method 1 is feasible in theory, but obvious limitations exist, such as the scenario where large files are being received from Interface 1, and the entire file has to be fully received before retransmission occurs, which leads to time delays and heavy loads being placed on the Samsung. Another limitation of Method 1 is the fact that there has to be sufficient flash memory capacity on the Samsung before the initial transmission of the file. In the event that there is insufficient flash memory capacity, mechanisms would have to be implemented to inform the client node of oversized files, which further increases the total transmission time to the destination node. The benefit of using this method is that files can be checked for integrity before retransmission and the chances of file corruption are minimized.

Method 2 is optimized for efficiency and retransmits data to the destination device as soon as it is received, which results in a significantly faster transfer time than if the file were to be received in its entirety as in Method 1. This method is also without the problem of the received file size exceeding the capacity of the Samsung. This is due to the fact that parts of the file are received, temporarily stored in buffers and then immediately transmitted from these buffers to the destination device. This Method cannot check files for integrity as with Method 1, due to the fact that only parts of the file are received and then immediately transmitted and forgotten about.

Regardless of whether Method 1 or Method 2 is used for *Blue Bridge*, it would be considered wasteful for a Bluetooth device to communicate with another Bluetooth device in range by forwarding all traffic through *Blue Bridge*, instead of establishing direct connections between one another. The primary function of *Blue Bridge* is to forward traffic from one interface to the other, and not to retransmit data on the same interface it was received on. Apart from application level receiving and forwarding, there needs to be a method by which *Blue Bridge* can inform nodes on both the Bluetooth and 802.11 wireless networks of one another. Subsection B proposes a very lightweight protocol, *Linkage*, which informs nodes of one another and controls the transmission and receiving between a node and the *Blue Bridge*.

B. Communication between nodes and Blue Bridge through Linkage

As mentioned above, the primary function of *Linkage* is to enable communication between nodes in one network and nodes in another, by making use of the central *Blue Bridge*. The most obvious approach to the implementation of *Linkage* is by programming the *Blue Bridge* node to broadcast packets to all nodes on either interface informing them of every other node. Broadcasting packets on a network is inefficient, and can consume the minimal bandwidth available in protocols such as Bluetooth. The way in which a broadcast protocol would work in this instance is for the *Blue Bridge* to broadcast a list of nodes within its range to every other node on the network. The *Blue Bridge* would have to periodically scan the network to determine which nodes are still in range, and then broadcast this information which could result in large amounts of network traffic where multiple *Blue Bridges* are concerned.

Although cellular networks in South Africa are expensive, the model which they employ with each cell phone having a number, is an ideal system to avoid broadcast traffic. Instead of having to maintain a database of nodes within range, we propose a system whereby nodes get assigned a number upon initial contact with the *Blue Bridge*. By employing this system, nodes can contact each other through the *Blue Bridge* by using a number which remains constant, thus eliminating the need for constant maintenance of nodes in range by the *Blue Bridge*. Figure 3 shows how nodes communicate using a number based system with *Linkage:*

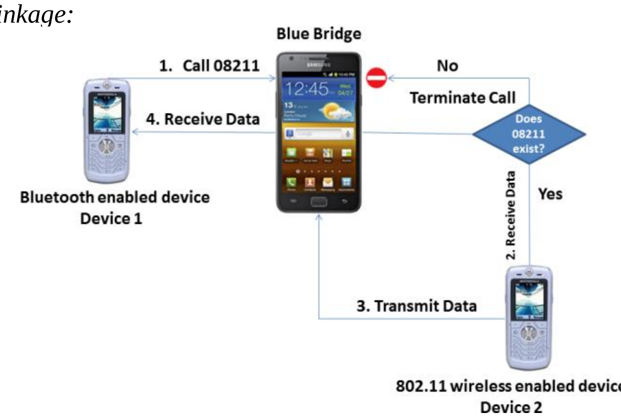

Figure 3. Linkage controlling a call between two phones

From Figure 3 it can be seen that Device 1 tries to establish communication with Device 2 by communicating through the *Blue* Bridge. Device 1 has its Bluetooth interface enabled and Device 2 has its 802.11 wireless interface enabled, which means that without the *Blue Bridge* communication between the two devices cannot take place. After the initial communication from Device 1, the *Blue Bridge* finds the associated address (either a Bluetooth or 802.11 address) and attempts to establish a connection. If Device 2 is unreachable after a certain timeout period, the call is terminated. If the *Blue Bridge* is able to reach Device 2, a connection is established and the data is transmitted from Device 1 through the *Blue Bridge* to Device 2. Of course if the type of connection were a voice call, Device 2 would have to transmit data to Device 1 through the *Blue Bridge* as well. The most crucial component to enabling communication between Bluetooth and 802.11 wireless devices is the allocation of a permanent number to each device from either network, which associates with the *Blue Bridge*. The assignment of numbers to devices is beyond the scope of this paper.

Figure 3 depicts how one 802.11 wireless device communicates with one Bluetooth device. The maximum number of active Bluetooth connections in one Piconet is 7, which limits the number of phone calls which can occur simultaneously through the *Blue Bridge*. Figure 5 shows an SDL diagram depicting the processes involved in handling simultaneous connections and ability of *Blue Bridge* to forward connections from one interface to another to reach the destination device. From Figure 5, it can be seen that *Blue Bridge* begins the bridging process by waiting for new connections. When a new connection is established, *Blue Bridge* determines whether the destination device is reachable. If the destination device either does not exist or is unreachable, the connection is terminated thus freeing up resources. If the destination device is found, the protocol with which the destination device and the *Blue Bridge* are communicating is determined. If the communicating protocol is 802.11 wireless, data is forwarded from the source device, through the *Blue Bridge*, to the destination device by implementing 802.11 wireless communication between the *Blue Bridge* and the destination device. If the communicating protocol is Bluetooth, the number of available connections is determined. This is necessary, since a maximum of 7 active Bluetooth connections can exist in the same Piconet. If the number of active connections is less than or equal to 7, then data is forwarded between from the source device, through the *Blue Bridge*, to the destination device by implementing Bluetooth communication between the *Blue Bridge* and destination devices. The above process is repeated until the concurrent Bluetooth connections is greater than 7, at which point 802.11 wireless communication will serve as the only means of communication for additional connections established.

With a proposed model for enabling Bluetooth and 802.11 communication highlighted in this section, the next section proposes a model built on top of *Blue Bridge* which aims to expand the reach of wireless networks.

V. NETWORK EXPANSION THROUGH SSID AND CHANNEL MATCHING AS A POSSIBLE EXPANSION

Although the primary focus of this paper is the proposal of an architecture which enables communication between the Bluetooth and 802.11 wireless protocols, this section proposes a model which describes the expansion of 802.11 wireless networks through *Blue Bridge* nodes, and hence the interconnection of these nodes, thus creating a community telephone network. According to [20] and [21], there are three prerequisites for the expansion of wireless networks: Identical SSIDs; Identical wireless encryption; and ideally the same wireless channel.

Android provides the ability to create wireless hotspots on a particular channel, with or without security (wireless encryption) enabled. With such functionality available, an existing wireless network could be expanded by creating a hotspot with the same SSID, on the same channel, with the same encryption. The *Blue Bridge* could enable inter-protocol communication as well as the expansion of wireless networks. The same principle could be applied to 802.11 wireless nodes running the Android platform, thus creating a wireless mesh network with minimal infrastructure.

Rural areas in South Africa are generally within range of nearby towns and cities, which allows for long distance 802.11 wireless links (50km) to bridge remote community telephone networks. Although there is no shortage of 802.11 wireless networks in South Africa, the idea of making use of existing networks for the purposes of this research would not be feasible due to a plethora of factors relating to network type (802.11a, 802.11b, 802.11g, and 802.11n) and the associated bottlenecks; open ports; and network names and channels. With that said, we have opted to implement our own low cost infrastructure to ensure availability and scalability.

In order to connect multiple *Blue Bridge* nodes across large geographical areas, directional antennas are proposed. Each *Blue Bridge* will connect to the directional antenna using the 802.11n wireless protocol. Figure 4 shows the interconnection of *Blue Bridge* via directional antennas:

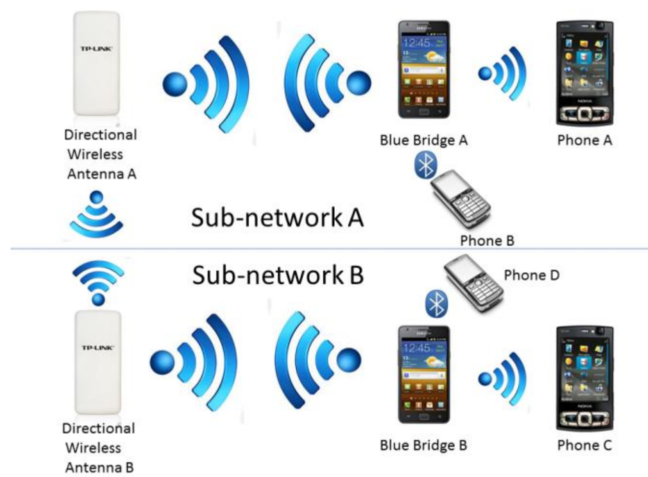

Figure 4. Interconnection of Blue Bridges

Figure 4 depicts two networks, Sub-network A, and Sub-network B, both of which are comprised of a directional wireless antenna, the *Blue Bridge*, and two cell phones. Sub-networks A and B enable communication between nodes in either network via the directional wireless link between Antennas A and B. *Blue Bridge A* enables access to the community telephone network via its 802.11 wireless and Bluetooth interfaces, thus enabling communication with Phone A and Phone B using the respective interfaces. Similarly, *Blue Bridge B* communicates with Phone C via the 802.11 wireless interface and with Phone D via the Bluetooth interface.

Although Sub-network A and Sub-network B can communicate via the wireless link between Antenna's A and B, this does not enable automatic communication between *Blue Bridge A* and *Blue Bridge B*. In order to facilitate the communication between the *Blue Bridges*, we propose the use of a dedicated registration server which keeps track of IP address assignments to each *Blue Bridge*. The registration server also handles the assignment of IP addresses to 802.11 wireless and Bluetooth based nodes connecting to the *Blue Bridge*. Since this paper focuses on bridging the 802.11 wireless and Bluetooth protocols, the operation and subsequent assignment of addresses to *Blue Bridges* and other nodes is beyond the scope of this paper.

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This section provided a brief overview of 802.11 wireless network expansion and showed yet another powerful aspect of the Android platform. This section also showed how high powered directional wireless antennas can be used to link multiple *Blue Bridges*. The next section concludes this paper.

VI. CONCLUSION

Although protocols such as Bluetooth are being used less in first world nations where the majority of mobile handsets possess 802.11 wireless capability, Bluetooth is a protocol, which is still widely employed in the African context. Bluetooth, although limited in terms of scalability, can serve as a point of access to community telephone networks for people with mobile handsets which lack 802.11 wireless capability. This paper showed how existing protocols can be combined through application level bridging on the *Blue Bridge* and the employment of the proposed protocol, *Linkage*. This paper highlighted the benefits and constraints of multiple methods of implementation and illustrated which method was chosen and why. This paper also proposed a future extension to the *Blue Bridge* which extends the range of wireless networks through SSID, encryption, and channel matching.

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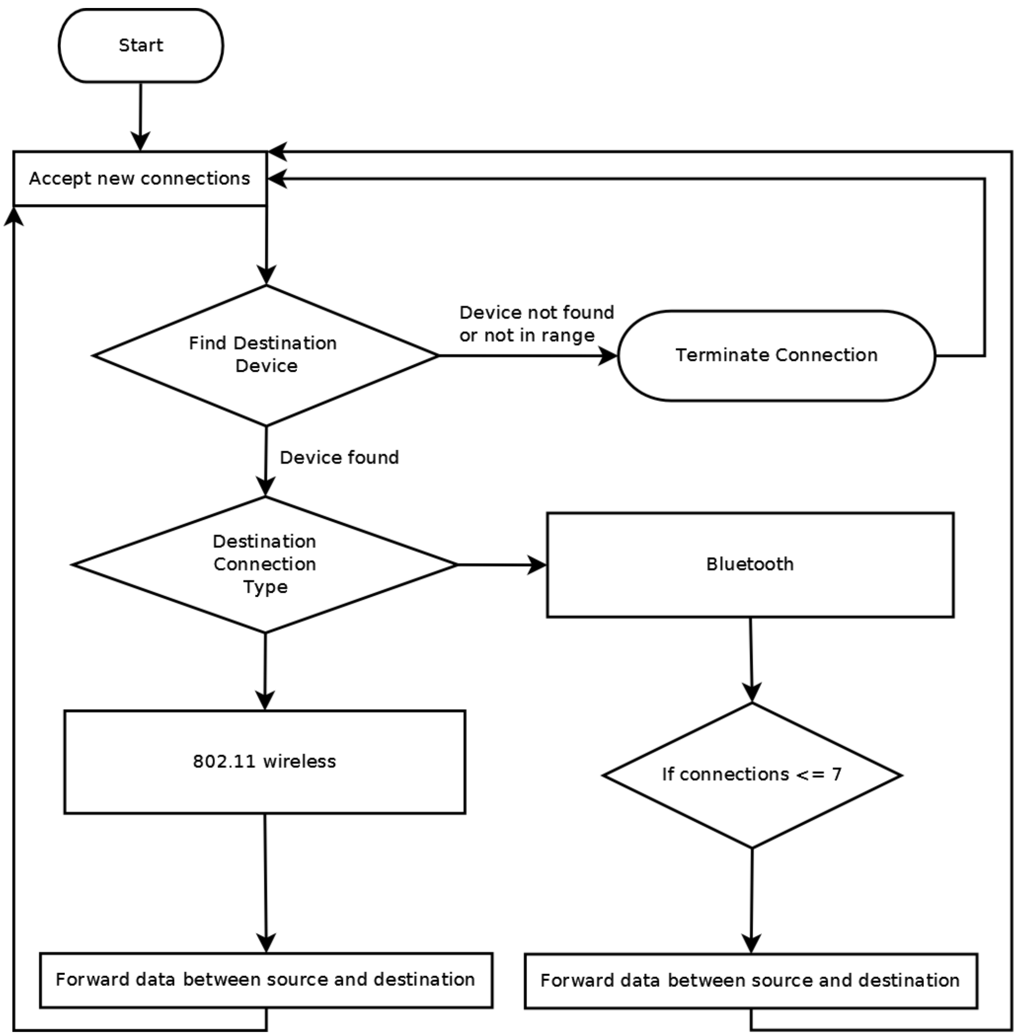

Figure 5. Blue Bridge processes and procedures

Network Topologies and Traffic Distribution Evaluation for Network Coding

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***Abstract*— In this article, we evaluate network coding algorithm COPE using different topologies, traffic intensities and distributions in order to search for guidelines for network deployments and for better exploring the advantage of network coding opportunities. Using different network topologies we identify nodes that perform well with coding and nodes that do not find any coding opportunities. Results show that in all analyzed networks, although the COPE performs well in decreasing average network delay, there are only few nodes that perform coding operations and up to 25% of nodes that find no coding opportunities at all. Also in, randomly distributed traffic, there is only a fragment of packets that find coding pairs, thus showing place for significant improvements either in used algorithms or in designing networks.**

Keywords-Network coding; COPE; simulation model; performance evaluation

I. INTRODUCTION

In the past few years, network coding (NC) has become popular in both, wired and wireless networks as a mechanism for increasing network throughput. Proposed by Ahlswede et al. [1], NC is a paradigm for encoding multiple packets either from the same or from different streams into the same packet in order to increase the throughput of the network. In wireless networks, NC can be used to exploit the broadcast nature of the wireless medium to enhance the effectiveness of several wireless channels and thus increasing the throughput of unicast traffic in wireless multihop (scenario) networks.

Whilst it is still not clear in which OSI layer the NC will find its place, in our opinion, it offers the largest potential in the network layer in strong collaboration with routing. This might lead to significant modification of routing concepts, as no longer shortest paths, or paths that avoid congestions will be looked for, but rather paths where NC principles can be fully exploited, thus increasing the network throughput capacity while maintaining the desired Quality of Service (QoS).

Presented paper deals with well known COPE algorithm described in details in [2, 3] as it is with MORE [4] the only algorithm that is considered to bring innovation to NC [5]. COPE is an intra-session NC algorithm. It codes packets for one hop, where packet decoding is done. The coding process depends on the nodes knowledge on what information (which packets) neighbouring nodes have. In case the node knows which information neighbours have (through listening to neighbours broadcasts (packets and ACKs) or receiving their updates) the coding process is straightforward and the decoding process will have a high success rate. Information arriving through particular massages and through listening to all the broadcast, is not sufficient and provides only few coding opportunities. In the case that the information on the packet presence at specific neighbour's node is not available the coding needs to guess on the situation. The node estimates probability that the node A has packet P, by looking at the delivery probability between packet's previous hop and node A. With all the needed information the node can code together as many packets as possible, as long as none of the packets have been created on this node, all the packets have different next hops and we know that there is a strong possibility that each next hop (all the neighbouring nodes that we are encoding packets in for) will be able to decode the packet. The next hop can decode the packet if it has already received all except one of the packets coded together.

We observe NC in different wireless network topologies and different traffic distributions and try to highlight where in the NC opportunities appear. We build networks around the nodes that can communicate with different number (i.e., 4, 6, 8) of neighbours, to see whether nodes with higher number of neighbours really have more coding opportunities as theory suggests. Such analysis has to best of our knowledge not been performed yet and it provides insightful information on the NC effects, where and why coding opportunities appear, thus providing a base for NC algorithm and protocol developers.

In the COPE presentation article [2, 3], the algorithm has been evaluated in the testbed in the outside environment using 20 nodes. Network was loaded using packet streams. The tests clearly showed that COPE significantly improves networks throughput, especially when the network is loaded with higher loads (congested network). Though, the testbed placed in the hardly controllable environment did not reveal the underlying process, thus constraining the chances for possible improvements on the algorithm or defining its possible lines of usage. Furthermore, the experiment is described insufficiently, thus not allowing repeating the results. Nevertheless, an accurate performance analysis of COPE is extremely challenging [6].

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COPE principle has been adapted and extended also for covering other ideas in NC: for example, in [7], noCoCo algorithm specializes in bidirectional traffic flows. It is trying to maximize the number of coding opportunities for the two opposite direction routes. CLONE [8] generalized COPE to address multiple unicast sessions. The system takes into account lossy links and highlights specific situations where COPE provides no coding gain. In [9] the MORE and COPE principles have been joint in search of benefits of the two at the same time.

Making routing aware of COPE coding opportunities has been investigated in [10] and [11]. In the first case, CORE, a coding-aware opportunistic (hop-by-hop) routing mechanism for wireless mesh networks, combines opportunistic routing by each route hop and localized inter-flow NC, increasing coding opportunities. In the second case, NJCAR, a network joint coding-aware (source) routing for wireless mesh networks, explore entire potential routes from source to destination in search for multiple hop decoding opportunities. Moreover, a new interference-avoid and coding-aware (ICM) routing metric is investigated in [12] for making tradeoffs between increased interference (due to multiple flows gathered together for creating coding opportunities) and increased coding gain.

While a significant amount of research has been done on better usage of the COPE there has been little words on its usability, e.g., in what kind of networks it is usable, where and why coding opportunities appear. The main reason for this is probably in rather unusual development and presentation of this excellent NC algorithm, which has initially been tested in close to real deployment environment.

This paper is organised as follows. Our NC simulation model used for obtaining the results is presented in Section II. In Section III, we present simulation parameters and briefly discuss simulation model. In Section IV, the results are presented and explained, while in Section V, we discuss results and give introduction into our further work.

II. NETWORK CODING SIMULATION MODEL

Simulation model [13, 14] consists of two major parts: the supporting network topology generator that reduces the manual work and main simulation model in OPNET [15] The network description program describes the desired topology, nodes, links and parameters for the communication stack (e.g., throughputs, number of packet retransmissions, loads, etc.). Network and its settings are then imported into the main simulation that takes place in the OPNET Modeler simulation tool.

As depicted in Fig. 1, the main simulation model is divided into five functional layers. Traffic Generation and traffic sink module is responsible for creating the network load and it also provides an end point for packets that have reached their destination. Routing module takes care of routing the packets through the network. The wireless module takes care of successful packet distribution through the wireless channel to the right address taking into account links conditions. Network coding module is the core of our simulation model and is responsible for coding multiple packets into one packet.

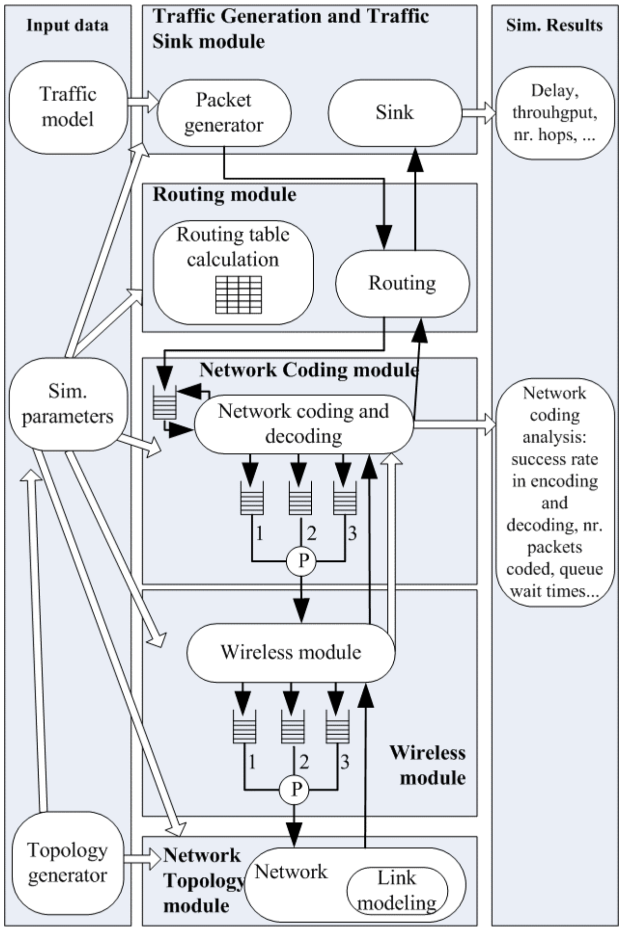

Figure 1. Network coding simulation model architecture.

A. Traffic module

Traffic module is responsible for loading the network with traffic. It allows evaluation of quality of service through measuring delay and amount of lost packets and quantity of service through throughput measurements.

The module supports two traffic distributions. In the first case, traffic is distributed throughout the entire network, where all nodes generate traffic and all nodes are destinations, while in the second case all nodes except their neighbours are destinations. Traffic intensity is set at each node individually.

B. Routing module

Routing module routes packets through the network. Looking at the packet's destination and given current location the module sets packets next hop.

Routing tables are calculated using Dijkstra's algorithm [16] taking into account distances between nodes, Expected Transmission Count (ETX) metrics or hop count.

C. Network coding module

In network coding module, COPE algorithm is implemented. The module has two functions. Its goal is to

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code as many packets as possible into one packet. When a module receives an encoded packet it tries to decode it. The module's success on decoding depends on the packets content and on the packets the module already has. The module has to own at least N-1 packets that have been coded into an encoded packet, where N is the number of all packets coded into the encoded packet. If the node can decode the packet it saves all the packets for later decoding purposes and it forwards to routing layer only packets destined to node's address.

In case module cannot decode the encoded packet, it discards the non-decoded packet and waits for the retransmission from the sender's side.

D. Wireless module

Wireless module takes care of successfully transmitting packets over the wireless medium. Using acknowledgement mechanisms it takes care of successful packet transmission.

In addition to using unicast transmissions where node that is the packet's recipient confirms successful reception with an ACK, we have also implemented a mechanism that boosts up effects of NC. It is a pseudo-broadcast, which has first been introduced by Katti et. all in [3]. This mechanism unicasts packets that are meant for broadcast. The link-layer destination field is set to the MAC address of one of the intended recipients (next hop of one of the packets coded into an encoded packet). Since all the nodes are set in the promiscuous mode, they can overhear packets not addressed to them. When a node receives a packet with a MAC address identical to its own, it sends an ACK massage to the sender. Regardless of packet's next hop address, the node sends the packet to the Network coding module.

E. Network topology module

The topology generator is developed in MATLAB [17] and it is able to generate random wireless topologies built around the arbitrary number of nodes that can communicate with different number of neighbours. The distribution of nodes is made in a random fashion within the predefined area. The connectivity between nodes is enabled based on nodes positions and transmission "range" of nodes. Selected topologies are then imported into the OPNET [15] simulation model with all the corresponding network parameters.

Nodes are connected with Point-to-Point receivers and transmitters to allow better topology control which is an important aspect in studying NC procedures. Even though, the connections are wired, they are modelled as wireless medium.

F. Link model

Link model can simulate various effects of wireless transmission. It can consider packet delay due to signal propagation through radio medium and transmission delay due to packet size and bandwidth used.

III. SIMULATION PARAMETERS

In our analysis, we assume that all network nodes have the same configuration as, e.g., in a homogeneous network. Networks with 20 nodes have been investigated, where each node has been given a random location within a given area. Node locations remain the same in all simulation scenarios.

Nodes that are connected (i.e., can communicate) to each other are presented with dashed lines between nodes in order to allow better topology control in the simulation. For each simulation scenario all the nodes in the scenario have exactly predefined number of neighbours i.e., $N_N = \{4, 6, 8\}$, while their position remains unchanged. As more scenarios (i.e., more different N_N) would be difficult to present and yielding no additional benefit, the representative scenarios with three different N_N were selected for presentation in this paper. A set of presented regular topologies above are useful in understanding the real advantage of NC. Two network topologies for N_N=4 and N_N=8 are presented in Figs. 2 and 3 respectively. Neighbour selection is mainly based on the node positions. For the simulation purposes all the links are symmetrical 1Mbit/1Mbit and are ideal, meaning that no packets get lost during transmissions and there is no additional delay due to propagation.

Traffic load is generated on all the nodes with the same intensity using exponential distribution of inter-arrival times and constant packet lengths (10 Kbit). Traffic distribution differs for Case 1 and Case 2, (results of both are presented in Section IV). In Case 1, all the nodes direct traffic to all nodes evenly (d1- distribution 1), while in Case 2 each node destines traffic to all nodes except to their neighbours (d2). By eliminating neighbouring nodes, as traffic destinations, a

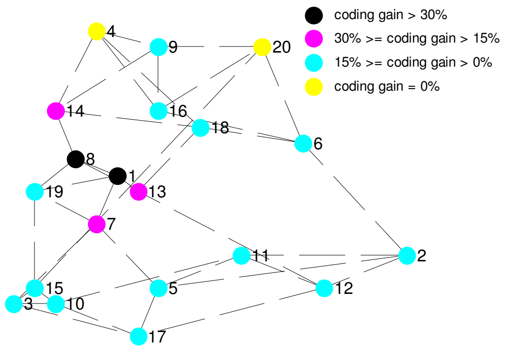

Figure 2. C4 network (N_N=4) presentation, with node categorization based on their coding success (d1, L1).

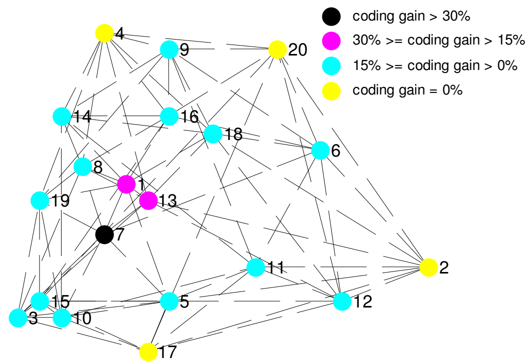

Figure 3. C8 network (N_N=8) presentation, with node categorization based on their coding success (d1, L1).

traffic distribution that is expected to affect coding opportunities has been introduced. Normalised network loads for Case 1 and Case 2 are presented in Table I and II, respectively. All the packets generated are upper layer packets (ULP) coming from layers above COPE.

TABLE I. HOP COUNTS (HC), DIAMETERS (D) AND NETWORK LOADS FOR ALL SIMULATION SCENARIOS FOR CASE 1

				Load(d1) (Mbits/s)			
		HC(d1)	***D***	***L1***	***L2***	***L3***	***L4***
Scenario	***C4***	2.76	7	6.9	4.6	3.4	2.7
	C6	2.01	5	9.4	6.3	4.7	3.8
	C8	1.76	4	10.7	7.2	5.4	4.3

TABLE II. HOP COUNTS (HC), DIAMETERS (D) AND NETWORK LOADS FOR ALL SIMULATION SCENARIOS FOR CASE 2

				Load(d2) (Mbits/s)			
		HC(d2)	***D***	***L1***	***L3***	***L5***	***L6***
Scenario	***C4***	3.23	7	5.9	3.9	2.9	2.3
	C6	2.48	5	7.6	5.1	3.8	3.1
	C8	2.32	4	8.1	5.5	4.1	3.3

Since coding opportunities depend on the amount of traffic in the network the load between the scenarios has been normalized in order to make scenarios comparable. The network with nodes that have more connections has smaller average hop distance to its neighbours. In scenarios described as d2, the packets make a longer trip to their destination. That means that with the same packet generator settings in the network with more connections per nodes would result in lower network load and in a case with different traffic distribution we would end up with different amount of network load. Thus, load (L) generated by traffic generators in the scenarios has been balanced according to the:

$$L_j * HC_{Ci} = const. \quad (1)$$

where HC is an average hop distance of traffic between sources and destinations in the network, j={1, 2, 3, 4, 5, 6} represents different loads, $i=N_N$ and, Ci denotes scenario with different topologies (i.e., C4, C6 or C8) and stands for connection per node. In Table I and II, the six used network average hop counts (HC) are presented. In addition, we are presenting also network diameters (D). Ci stands for connections per node, i.e., N_N in the particular scenario.

Tables I and II also show the average traffic load generated in the upper layers at all the nodes together for a particular scenario. This resulted in the comparable network throughputs in scenarios using different N_N.

Routing of packets through the network was done using static tables which were calculated ahead of simulation runs.

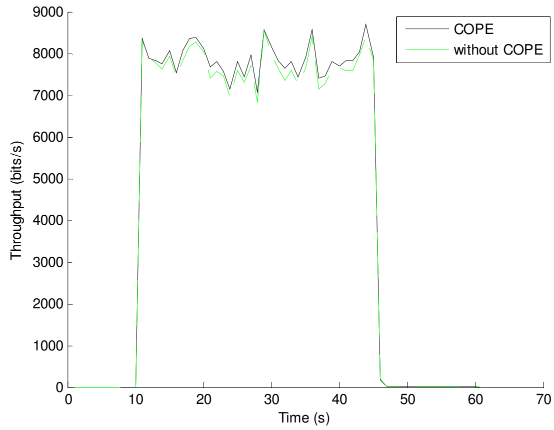

Figure 4. Network throughput for C6, L3, in case of using COPE and without COPE.

Routing tables are calculated using Dijkstra's algorithm taking into account distances between nodes.

As seen from Fig. 4, every simulation run took 60 seconds. The network initialization phase took 10 seconds. The traffic was generated between the 10^{th} and 45^{th} second. Results were collected only between 11^{th} and 44^{th} second in order to observe steady state conditions. All the packets arriving after that time were not included into results. Running simulations for a longer period than loading the network with traffic allows easier recognition of a steady state conditions.

IV. SIMULATION RESULTS

The NC simulation has been used to obtain numerous simulation results considering different combinations of simulation parameters described in Section III. In the following, the most representative results are displayed, obtained for COPE scenarios and also for no-NC case scenarios as a reference (i.e., without COPE). With the help of all the presented results, one can also make a lot of conclusions on its own.

The results are presented in Figs. 5 and 6 for quality of service (user) point of view, and grouped in Tables III and IV according to their relevance for quantity of service (operators' point of view) and evaluation of COPE algorithm itself. As described in Section III, we have three different networks that differ in number of neighbouring nodes: 4 ('C4' in table), 6 ('C6'), and 8 ('C8'), namely. Each network has been loaded with four different traffic loads (L1 > L2 > L3 > L4) in a way that a complete network is handling the same network load for different number of connections (see Tables I and II).

A. Case 1 Traffic Distribution

First, we present results for the Case 1. As already mentioned in Section II, in this case, all the nodes send packets to all nodes evenly.

1) Average End-to-End delay

From the quality of service point of view we measured the average End-to-End delay in the network. Each packet

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that arrived to its destination node (between 10th and 44th second) was included in the statistics. We measured the delay between source node and destination node for every ULP packet. We have done so also in the scenarios without COPE. Delay results are represented graphically for all combinations of networks and loads in Fig. 5 (note logarithmic scale), where measurements are marked with signs, while connections between them have been made only for visualization purposes.

2) Coding Gain

From the COPE point of view we looked at COPE packet distribution and we have arranged COPE nodes according to their success in coding.

Packet distribution shows how much (%) ULP packets were encoded into the COPE packet (1 to 4 packets - there were no occasions of coding more than four packets into one COPE packet).

Node successfulness in coding further explains coding opportunities. We have divided nodes into four categories based on their success in coding packets together. Coding gain (G) for each node defined as the ratio between the number of source packets (without coding) N_S and the number of packets required to send source packets with coding N_C [3] has been used as a measurement:

$$G = \frac{N_S}{N_C} \tag{2}$$

For the gain representation, thresholds of coding gains have been set at 1.3, 1.15 and 1, representing 30 (higher G), 15 (medium G), and 0 (no gain) percent of packets being coded on particular node.

3) Network Throughput

Quantity of service results deal with network throughputs. We present the traffic throughputs as observed in the 802.11 layer. In Fig. 4, the network throughput for C6,

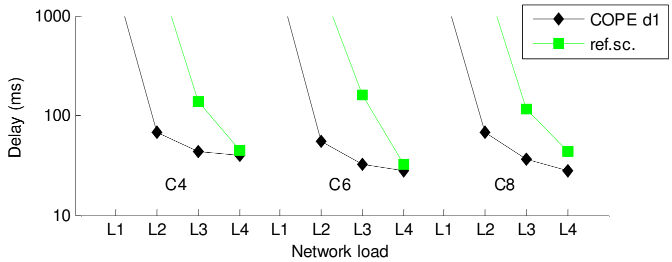

Figure 5. QoS of Case 1 - End–to–End delay for different loads in all of the observed topologies for nodes using COPE and for reference without COPE.

TABLE III. SIMULATION RESULTS FOR CASE 1

		COPE d1							Quantity of service			
		Packet distribution (%)			*Node successfulness in coding (Nr.)*				*Distribution of average network load (802.11) η(%)*			
		1 ULP	*2 ULP*	*3 or 4 ULP*	*G>30% for d1*	*15%<G<=30% for d1*	*0%<G<=15% for d1*	*G=0 for d1 (no coding)*	*COPE d1*	*without COPE*	*COPE d1*	*without COPE*
									(high)		*(medium)*	
C4	*L1*	78.8	21.2	0.0	2	3	13	2	60	65	20	10
	L2	85.8	14.2	0.0	2	2	15	1	35	40	25	20
	L3	92.7	7.3	0.0	0	2	14	4	15	25	30	20
	L4	95.6	4.4	0.0	0	0	16	4	5	15	20	10
C6	*L1*	80.4	19.6	null	3	4	9	4	70	65	25	25
	L2	90.4	9.6	null	1	2	13	4	40	40	25	20
	L3	95.2	4.8	null	0	1	13	6	15	15	30	30
	L4	97.2	2.8	null	0	0	14	6	5	10	15	15
C8	*L1*	81.5	16.7	1.8	3	4	9	4	70	70	30	30
	L2	89.6	10.0	0.4	1	2	13	4	30	35	30	25
	L3	94.9	5.0	0.1	0	1	13	6	20	20	15	15
	L4	97.1	2.9	0.0	0	0	14	6	10	10	15	15

L3 (random) scenario is presented as it varies thorough time during the simulation. Similar, the time variation in other case scenarios is behaving. In Tables III and IV, in "Distribution of average network load" column 802.11 load measurement results on all the links in both directions are presented. We have been interested in two types of links, those with high load (average load more than 90% of link capacity) and those with mint load (average load more than 70% and less than 90% of the link capacity). To be able to compare results between the scenarios we present results as ratio of links that meet criteria and all the links in the network:

$$\eta = \frac{Nr\ of\ Links\ to\ meet\ criteria}{Nr\ all\ links} \qquad (3)$$

4) Results interpretation

From Fig. 5, we can see that in given conditions the delay is significantly smaller when COPE algorithm is used. This is especially notable when in the scenarios without COPE the network is not able to handle so high network load (noted also in figure with no mark, representing infinite delay). This is expected as with higher loads there are more packets in queues, increasing the chance for algorithm to find co-codable packets, thus taking them from the queue ahead their turn.

We can also notice that end-to-end delay is decreasing while increasing the number of connections nodes have. This is once more expected as the average hope distance between nodes is smaller in networks where nodes have more connections. Equally distributed load (from each node to all the nodes) per average has to take a shorter path to its destination, thus resulting in lower delay.

The results show that there are only few coding opportunities for a given traffic distribution. Even though in all scenarios for L1 the network was congested, only a fragment of packets from upper layers is codable with other

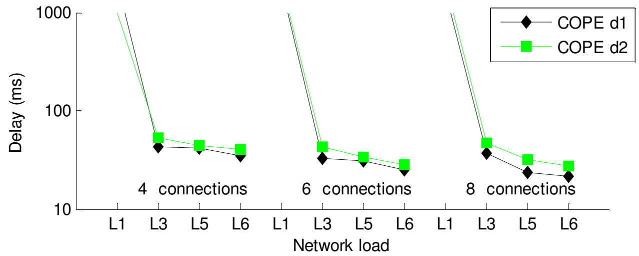

Figure 6. QoS of Case 2 - End–to–End delay for different loads in all of the observed topologies for nodes using COPE with two different traffic distributions.

TABLE IV. SIMULATION RESULTS FOR CASE 2

		COPE d1		COPE d2		Node successfulness in coding (Nr.) for L1						Quantity of service			
		Packet distribution (%)										Distribution of average network load (802.11) η(%)			
		2 ULP	3 or 4 ULP	2 ULP	3 or 4 ULP	G>30% for d1	G>30% for d2	15%<G<=30% for d1	15%<G<=30% for d2	G=0 for d1	G=0 for d2	COPE d1 (high)	COPE d2 (high)	COPE d1 (medium)	COPE d2 (medium)
C4	L1	21.2	null	22.2	null	2	4	3	2	2	3	60	55	20	20
	L3	7.3	null	9.2	null	0	0	2	3	4	3	15	20	30	30
	L5	3.0	null	4.0	null	0	0	0	0	5	7	0	0	15	20
	L6	1.6	null	2.1	null	0	0	0	0	9	9	0	0	0	5
C6	L1	19.6	null	22.9	null	3	3	4	4	4	4	70	60	25	20
	L3	4.8	null	6.3	null	0	0	1	1	6	6	15	15	30	25
	L5	1.8	null	2.5	null	0	0	0	0	7	6	0	0	15	15
	L6	1.0	null	1.3	null	0	0	0	0	9	8	0	0	0	5
C8	L1	16.7	1.8	21.2	2.6	3	3	4	4	4	4	70	60	30	10
	L3	5.0	0.1	8.7	0.2	0	0	1	1	6	6	20	20	15	15
	L5	1.7	0.0	3.6	0.0	0	0	0	0	7	6	0	5	20	15
	L6	0.9	0.0	1.8	0.0	0	0	0	0	9	8	0	0	0	10

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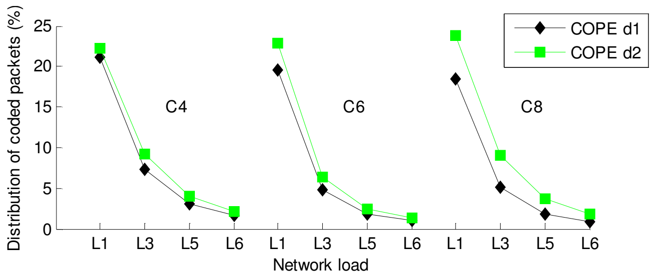

Figure 7. Case 1 and Case 2 - Share of COPE packets carrying more than one ULP packet.

packets (21.2 % is the highest rate in all scenarios). Also there were only few opportunities to code together more than two packets into one COPE packet. The results clearly show that coding opportunities for coding more than two packets together appear more often in networks where nodes have more connections (higher N_N). Furthermore, while increasing the number of connections per node in the network, share of packets carrying more than one upper layer packet decreases. This can to a certain point be explained with the load distribution: the average hop distance is lower, making average packet path shorter, while knowing that packets are in the first hop not codable. Though, more connections mean more overheard packets, more neighbours and thus higher chance of finding packets that can be coded together.

B. Case 2 traffic distribution

In the Case 2, we have tried to decrease the effect of smaller average network HC with networks that have nodes with more connections by introducing different traffic distribution (d2); all nodes send packets to all nodes except to their neighbours (see also Section III). In Fig. 6, we can see that end-to-end delay is increased with the d2 distributions. This is expected as the packets per average had to take a longer path than in d1 traffic distribution.

In Table IV, the results show that there are only few coding opportunities also for d2 traffic distribution, as compared to d1. In all scenarios for L1, the network was again congested, but only almost 23 % is the highest fragment of packets from upper layers that were codable with other packets. Furthermore, we can see in Fig. 7 that the load distribution has little effect on the coding opportunities. Even though, all the packets sent into the network are codable at least half their way there has been only a small increase of coded packets. The difference becomes apparent only with higher loads (e.g., L1). If compared to d1 in d2 there is almost no variation in coding success when number of node neighbours is changed, thus indicating that there is almost no difference in finding coding opportunities for different network topologies as used in this article.

C. Summary of the results for Case 1 and Case 2

For both traffic distributions we can see that in majority of scenarios there are only few nodes that perform very well or above average in coding. The number of these nodes slowly decreases with the number of connections nodes have. And quite the opposite with networks with higher number of connections per node there are more nodes that do not perform any coding at all (COPE packets carried only one ULP packet) or manage to code packets only occasionally. The situation can further be analysed in the Figs. 2 and 3 for d1, where nodes that are darker had more coding opportunities, while the lightest coloured nodes (i.e., yellow) have not coded any packets together. In Fig. 3, we have a network where each node has eight connections. Around the "node 7" (black node) there are two more nodes that perform majority of coding, that is also the part of the network that presents the bottleneck. Nodes that do not perform any coding are stationed on the network edges. Fig. 2 shows the same situation in case of network where nodes have four connections (N_N =4). There are two nodes that do well in coding packets and there are less nodes that do not perform any coding. If we divide the network into "subnetworks" we can once more claim that nodes that do not perform coding are placed at the network edges, while nodes that perform better, act as links between individual "subnetworks". For d2, the results of analysis are in line with d1 analysis.

Even though the total network throughput is increased the COPE helps "balancing" the network load. This can be seen from Tables' III and IV column "Distribution of average network loads". Results show that in case of higher loads, COPE is able to distribute the traffic amongst more nodes and thus keep the network congestion free. There are more nodes in COPE case with medium loads than in case without COPE. This means that congestions happen when coding is not used and traffic is delayed, thus making links that are not congested even less loaded. COPE, in the case of sudden bursts, finds more coding opportunities, thus coding more packets together, while using the same bandwidth and thus avoiding congestion.

V. CONCLUSIONS AND FUTURE WORK

We evaluated NC algorithm COPE using different topologies, traffic intensities and distributions. The results show that COPE NC algorithm improves the network throughput in all analysed networks with given traffic distributions. Most importantly, in the high load situations when in case without COPE the network can not carry the load and thus the delay is infinitive the network still handles its load. Results once more show that this intuitive algorithm COPE really helps improving the network capacity.

Still, our results show that there is a lot of space for improvement. In our random traffic load conditions only a fragment of packets found pairs to be coded to. Even more,

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cases when more than two packets got coded together hardly ever happened.

We have been looking for correlation between success ratio in coding and number of neighbours that nodes have in the network. Theoretically nodes with more neighbours should be able to code together more packets, thus reaching higher coding gains. Results of the simulations show the opposite; networks where nodes had fewer neighbours had more success in coding, by comparable network load conditions. This happens as hearing more neighbours means having more connections per node when distributing network traffic. In such situation, nodes have lower average hop distance to destinations and thus fewer chances to code packets together.

Analysis of individual nodes and their success in coding also reveals that there are only few nodes that perform coding operations, while there were a lot of nodes that did not manage to find any co-codable packets. Moreover, nodes that are placed in the heart of the network and do have many neighbours did not find coding options for coding more than three packets into one COPE packet. Overall, we had one to three nodes per network that were very successful in coding but up to 30% of nodes that have not managed to perform any coding operations.

Overall, results show that coding opportunities arise with increased traffic. In highly loaded network, there is significantly less coding opportunities than in congested network.

In depth analysis of NC can help us better understand where and why coding opportunities appear. The results imply that implementation of NC can result in modifications and possibly new approaches in NC, affect heavily routing concepts, or just provide guidelines on network planning is still a question.

In our opinion, mainly based on presented results the biggest opportunity for NC lies in strong collaboration with routing. If traffic is acting randomly as in our case, NC can not reach its full potentials, therefore different approaches in traffic organisation should be looked for, thus making routing be aware of coding opportunities, rather than being oblivious to it.

As future work, we consider implementing other existing NC algorithms for further evaluation of NC principles. Furthermore, on the basis of the results and analyses presented in this article we intend to develop new NC algorithms and routing schemes for NC. With respect to the simulation model, additional modules, which will take into account also more realistic wireless links, will be implemented.

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A Survey on QoS in Wireless Mesh Network

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***Abstract*— The wireless mesh network is a new emerging technology that will change the world of industrial networks connectivity to more efficient and profitable. Mesh networks consist of static wireless nodes and mobile customer; have emerged as a key technology for new generation networks. The QoS is designed to promote and support multimedia applications (audio and video), real time (ToIP, VoIP). However guarantee of QoS on wireless networks is a difficult problem by comparison at its deployment in a wired IP network. The reason is the random mobility of nodes, the nature of wireless channel (interference), the multi-hop communication and the lack of a central coordinating authority. Wireless Mesh Networks (WMNs) are commonly considered the most suitable architecture because of their versatility that allows flexible configurations. Different studies have proposed number of protocols in different layers of model TCP/IP to enhance transmission of data and its QoS. This paper mainly focuses on classification layer of the largest existing approaches dedicated to QoS. It is also discussing the most interesting works on QoS in WMNs networks.**

Keywords-WMN; QoS; TCP/IP; Routing protocols.

I. INTRODUCTION

The Internet in the near future will be everywhere and offer broadband today, that we have never experimented. Networks invade all sectors with individuals and organizations always interconnected private networks and connected to the internet.

These networks aim to provide a wide range of beneficial social functions: individual medical monitoring in urban and rural make up and support business projects effectively. The WMN is a promising candidate for the implementation of such connectivity, also known for its ease of deployment.

A group IEEE 802.11s was created in January 2004 [1] to provide benefits and features of the mesh network architectures and IEEE 802.11 protocols. More specifically, to define the necessary amendments at the MAC and physical layers to create a wireless distribution system based on IEEE 802.11 technology.

WMN self-organizing and self-configure increases the coverage of wireless LAN standard (802.11n) to the wireless mesh MAN (802.11s) without significant additional infrastructure deployment. It also offers a good platform for promoting social partnerships in urban and rural areas.

In the non-meshed WLANs, stations must associate with an access point (AP) to access the network, and these stations depend on this access point with which they have come together to communicate. In a mesh APs can communicate with each other directly without going through an external network. [1]

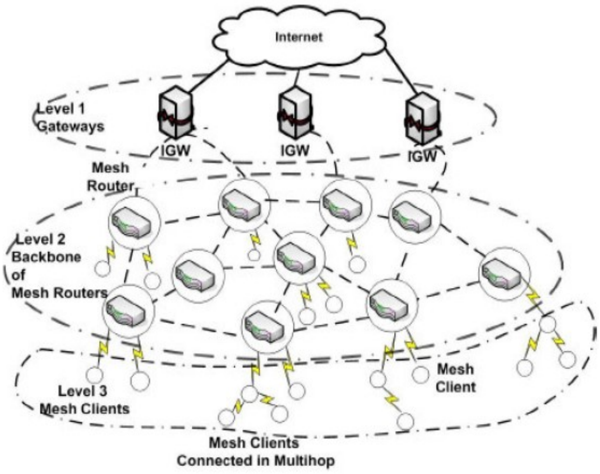

Figure 1. WMN architecture

An example of mesh networks is illustrated in Figure 1. In fact, a mesh network is divided into three parts:

- The first level is generally distinguished gateway nodes for wireless mesh nodes passed to external networks such as Internet, GSM, WiMax, etc

- The 2nd level is the mesh nodes (wireless AP) that are usually fixed to create the skeleton of 802.11s wireless network and serve the 3rd level.

- The 3rd level is composed of Mesh customers; these customers are often mobile and use services via the 802.11s.

The remainder of the paper is organised as follows. First, we discuss about WMN uses in different cases, second is an introduction to our analyzes and comparisons in Section 3. A network layer approaches is explained in Section 4. A link layer approaches is presented in Section 5. At last, a physical layer approach is elaborate in section 6, with a global concluding and remarks in Section 7.

II. THE IEEE 802.11S USES

The wireless mesh network defines four possible deployments: residential deploying for the digital home, deployment for a company as WLAN, deployment in public places to allow access to the internet and finally as temporary wireless network infrastructure disaster.

In the residential case, the mesh network, also called the digital home, will create low cost and ease of deployment with an excellent wireless coverage in all

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floors of the house. The main motivation behind the introduction of mesh networks to provide connectivity in the company is to use a wireless technology performance, reliable, inexpensive and easy to deploy. This allows companies to control costs associated with network installation and reduce the time required for deployment but also guaranteeing mobility for employees.

III. Approaches for QoS in Wireless Mesh Network

Different approaches have been proposed by the state of the art spread over the different layers of the TCP / IP, we will summarize the most interesting in the following section.

IV. A Network layer approaches

As WMNs become an increasingly popular replacement technology for last-mile connectivity to the home networking, community and neighborhood networking, it is imperative to design an efficient resource management system for these networks. Routing is one of the most challenging issues in resource management for supporting real-time applications with stringent QoS requirements.

In general, there are two main kind of routing protocols for multi-hop wireless networks: (i) topology-based protocols which need topological information to set up a path between the nodes, (ii) position-based protocols which require some geographical information for the route discovery process. Among the topology-based routing protocols considered here, two distinct categories can be defined:

Proactive which maintain the information about the routes to every node all the time by sending periodic updates even if the nodes do not communicate with each other, including DSDV (Destination-Sequenced-Distance Vector),OLSR (Optimized Link State Routing) and MPR (Mesh Networking Routing Protocol)

Reactive called also 'on-demand' for which the paths are computed and maintained only when needed, including AODV (Ad-hoc On-demand Distance Vector), and DSR (Dynamic Source Routing) [2].

DSDV ([3], [4], [5]). It is a modification of Bellman-Ford algorithm implemented in RIP (Routing Information Protocol) adapted for self-configuring networks. Every node maintains its own routing table with the information about network topology and the cost of the links between the nodes.

OLSR ([6], [4], [5]). It uses shortest-path algorithm having the access to the routing information whenever it is needed (storing and updating periodically). The optimization idea is based on specific neighborhood detection and Multipoint Relays (MPR-s) selection concept.

MRP [9]. In this protocol each client is chosen a gateway to connect to the internet. If the gateway fails or the node moves, the node will choose a different gateway. All the traffic is assumed to flow through the gateway to the internet. This protocol is mainly available in three versions. One of the versions is MRP on-demand.

AODV ([7], [4], [5]). It uses Route Request/ Route Reply (RREQ/RREP) mechanism for route discovery and destination sequence numbers for each route entry like DSDV. This helps detecting outdated routing. Moreover, it keeps track of the next hop instead of the entire route.

DSR ([8], [4], [5]). Similarly to AODV, it is based on RREQ/RREP packets. However, RREQ gathers the addresses of the 'visited' nodes and maintains information about the whole path from the source to the destination node, not just the next hop. Moreover, the information is stored by every node in a route cache instead of the routing table.

Several studies have compared the routing protocols used in most networks Mesh, to find, expand and improve those who gave the best results; the most recent are listed below.

A. Analysis of Routing Protocol Performance in Wireless Mesh Networks

This work [2] is divided into two parts: the first part, the compared protocols are: AODV, DSR, DSDV and OLSR, using a fixed topology and other mobile on wireless mesh network with NS -2. The results show that the protocol AODV is the best in terms of delay, throughput and that the DSR is the worst among the four protocols mentioned.

Furthermore, the authors introduced TCP and UDP in the scenarios of the first part, to assess the degree of impact of the transport layer at the network layer. The results confirm that UDP is more interesting than TCP in terms of QoS management.

There is no ideal and the best routing recommendation for WMN. From the protocols studied in this paper, OLSR and AODV should be considered as the ideas worth considering. However, scalability is one of the crucial problems also in this case. One of the solutions is to propose a new routing metric for the existing protocols, use hybrid routing techniques or/and multiple radios and interfaces in order to improve performance of the network and provide better capacity of the network

B. R-AODV Rate Aware Routing Protocol for WMN

After our previous analysis and existing literature, the routing protocol AODV is most advantageous to ensure QoS, and naturally, lot of works was directed towards the extension of AODV, to improve its performances. It is the aim of the paper [10]. Rate aware routing protocol based on AODV (R-AODV) [9] uses minimum network layer transmission time as a performance metric. Nodes will select higher data rate link using R-AODV.

The simulation result indicates that R-AODV can improve the network throughput and decrease network delay.

C. *Optimization of routing algorithm in WMN*

For specific application like, emergency or search and rescue operations in case of natural disaster, policing and fire fighting military applications such as on the battle field, meeting rooms, sports stadium etc, almost all routing protocols in one way or other, try to converge into shortest path routing. One of the advantages of using shortest path routing is that it is good for overall energy efficiency because energy needed to transmit a packet is directly proportional to path length or number of hops. But the shortest path routing is restricted to use the same set of hops to route the data packets, thus causing some of the heavily loaded nodes and thus causing some of the nodes to die earlier resulting into holes in the network or even worst into partitioning of the network. Thus the need for load balanced routing emerges.

Authors in [11] formulate the problem of routing as a network optimization problem, and present a general LP (linear programming) formulation for modeling the problem. The authors propose the optimized algorithm for known traffic demand and then explain the performance ratio for this. The routing algorithms derived from these formulations usually claim analytical properties such as optimal resource utilization and throughput fairness. The simulation results demonstrate that their statistical problem formulation could effectively incorporate the traffic demand uncertainty in routing optimization, and its algorithm outperforms the algorithm which only considers the static traffic demand. To achieve this objective the problem for congestion has been designed.

D. *A Throughput Optimizing Routing Protocol for Wireless Mesh Networks*

The goal of the proposed routing protocol [12] is to establish a route from the source to the destination that allows traffic flow within a guaranteed end-to-end latency using the minimum control overhead. The protocol is based on a reliable estimation of wireless link quality and the available bandwidth on a routing path. It also minimizes control overhead by effectively controlling broadcast messages in the network. The QoS-awareness in the protocol is achieved by a robust estimation of the available bandwidth of the wireless channel and a proactive discovery of the routing path by an accurate estimation of the wireless link quality. In addition, the protocol uses the multi-point relay (MPR) nodes to minimize the overhead due to flooding.

The key contributions of the paper are as follows: (i) it exploits the benefits of using MPRs and circular routing to increase the network throughput by reducing the control overhead. (ii) It computes a link quality estimator and utilizes it in route selection. (iii) It provides framework for reliable estimation of available bandwidth in a routing path so that flow admission with guaranteed QoS satisfaction can be made. It also ensures that the number of retransmission required is minimized.

E. *Routing Packets into Wireless Mesh Networks*

On the forward path, from mesh nodes to Internet nodes, for all mesh nodes only route information for one destination, the gateways, needs to be maintained. However, on the backward path from the Internet to mesh nodes, an individual route for every mesh node is required.

In [13], the authors investigate protocols for backward path routing in wireless mesh networks. Using simulation experiments with realistic mobility patterns of pedestrians and cars in cities, they compare three protocols, each of which represents a routing protocol family: (i) AODV with an extension for mesh networks, a reactive routing protocol, (ii) FBR, a proactive routing protocol, and (iii) GSR, a source routing protocol. Their results indicate that FBR has the highest packet delivery ratio but is not scalable to the network size. The extended AODV seems to be neither scalable nor does it achieve a high packet delivery ratio. A good compromise is provided by GSR, which is the most scalable.

F. *Backup Routing for Multimedia Transmissions over Mesh Networks*

Liu et al. [14] proposed an available bandwidth estimation algorithm plus a QoS backup route mechanism to accommodate multimedia traffic flows in mobile wireless mesh networks. Moreover, to validate the correctness of our proposed algorithm, the authors have implemented the algorithm on the campus wireless mesh network testbed. Their implementation and experiments show that their mechanisms can improve the network stability, throughput, and delivery ratio effectively, while decreasing the number of route failure. They implement their proposed algorithms on the testbed through an improved DSR protocol. Their implementation and experiments show that the mechanisms can effectively improve the network stability, throughput, delivery ratio, while decreasing the route invalidation ratio, and can guarantee the fluent transmission of multimedia streams.

In order to support multimedia transmission with QoS requirements, they improve the wireless routing protocol on the testbed with a dynamic ACK mechanism, which is used to balance the throughput and the quality of transmission. Additionally, authors introduce a dynamic mechanism to change the

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multimedia coding rate dynamically at the source node according to the available bandwidth. Moreover, they also made improvement on the admission control protocol to facilitate an experiment.

G. *Efficient Routing Anomaly Detection in Wireless Mesh Networks*

The throughput of a WMN may be severely degraded due to presence of some selfish routers that avoid forwarding packets for other nodes even as they send their own traffic through the network. Jaydip Sen. [15] presents an algorithm for detection of selfish nodes in a WMN.

It uses statistical theory of inference for reliable clustering of the nodes and is based on local observations by the nodes. Simulation results show that the algorithm has a high detection rate while having a low rate of false positive

H. *Algorithm for Congestion Control in Wireless Mesh Network*

Congestion control is an important research area in wireless mesh network (WMN). In order to solve congestion control in WMN, a random routing algorithm based on path weights (WA) is presented. The algorithm adopts multi-gateway wireless mesh network routing protocol to solve the congestion problem of single gateway.

And any cast service was used to ensure the successful rate of service requests. Simulation results show that WA is the better algorithm as it has less average wait time and the successful rate of service requests. The algorithm can effectively solve congestion problem, and make the network stable and efficient.

I. *A new vision of routing protocol*

The mesh network, as is a special case of Ad-hoc networks and MANET networks. These include a new vision of routing protocols based clusters, whose principle is very simple: divide the whole network into several parts, each party will elect a central node, responsible for coordination of routing information between other adjacent nodes, that node is named CH (Cluster Head), other nodes called its members.

Communication in this type of network is simple, any member wishing to transmit, do it through its CH. The latter has a routing table, if the destination is internal (in the same group), then the delivery will be direct, if not the CH sends queries to neighbors to find the right path.

Very recent works have focused on this type of MANET routing. Mukesh Kumar [16] compared a routing protocol named CBRP (Cluster Based Routing Protocol) which gave results much interest as the basic protocols in terms of QoS (delay, throughput) and a good transition to across the MANET.

J. *Conclusion*

The first assertion that we can do, is that, according to the comparative studies results, done to determine what is the best choice between the existing routing algorithms in the state of the art, AODV and OLSR are the best choice by report to others, in terms of QOS.
The second assertion is that several trends have emerged, as follows:

- Extending the traditional routing algorithms such as AODV, DSR, OLSR, to improve their performances.
- Changing values of the metric, like hybrid or dynamic metric, as bandwidth of links, or end-to-end latency instead of number of hops, for example.
- Propose protocols completely different from those present in the802.11s standard
- Use of the clustering approach

V. A LINK LAYER APPROACHES

MAC protocol design is important in meeting QoS requirements since much of the latency experienced in a wireless network occurs in accessing the shared medium. In addition, MAC protocols must be interoperable with existing wireless networks operating on the same RF spectrum and fair toward all users.

A. *A Distributed QoS MAC Protocol for Wireless Mesh*

Abundant hidden node collisions and correlated channel access due to multi-hop flows degrade QoS in wireless mesh networks. QoS in nearby WLANs operating on a single channel is also affected. Mathilde Benveniste [17] propose using wider contention windows for backoff to lower the risk of repeated hidden-node collisions, a spatial extension of the TXOP concept called 'express forwarding' is an enhancement of the CSMA/CA protocol designed to reduce the latency experienced end-to-end by a multi-hop wireless mesh to clear multi-hop flows sooner, and a new mechanism called 'express retransmission' to reduce collisions on retransmission. Simulation results show the potential benefit of the proposed enhancements and impact on fairness.

B. *A Novel Spatial TDMA Scheduler for Concurrent Transmit Receive WMN*

A key approach to increasing network capacity is to equip wireless routers with smart antennas. These routers, therefore, are capable of focusing their transmission on specific neighbors whilst causing little interference to other nodes. This, however, assumes there is a link scheduling algorithm that activates links in a way that maximizes network capacity. To this end, Chin et al. [18] propose a novel link activation algorithm that maximally creates a bipartite graph, which is then used to derive the link activation schedule of each router.

Authors verified the proposed algorithm on various topologies with increasing node degrees as well as node numbers. From extensive simulation studies, authors find that their algorithm outperforms existing algorithms in terms of the number of links activated per slot, super frame length, computation time, route length and end-to-end delay.

C. A Real time Video Stream Aggregation in WMN

Navda et al. [19] design and evaluate Ganges, a wireless mesh network architecture that can efficiently transport real time video streams from multiple sources to a central monitoring station. Video quality suffers from deterioration in the presence of bursty network losses and due to packets missing their playback /deadline. Ganges spatially separates the paths to reduce inter-flow contention. It finds out a fair rate allocation for the different video sources.

The wireless routers in the mesh network implement several optimizations in order to reduce the end-to-end delay variation. Ganges improves the network capacity by a shortest path tree, and video picture quality by Central.

D. On the Support of Multimedia Applications over 802.11s

The contribution of this work [20] is twofold. First Riggio et al. propose a methodology for evaluating multimedia applications over real world WMN deployments.

Second, based on the defined methodology, they report the results of an extensive measurement campaign performed exploiting an IEEE 802.11-based WMN testbed deployed in a typical office environment. The focus of their research on three mainstream multimedia applications: VoIP, Video Conference, and Video Streaming. Two single-hop star-shaped network topologies (with symmetric and asymmetric links) and a multi-hop string topology have been exploited in order to provide a comprehensive evaluation of the testbed's performances.

E. Enhancing Video Streaming in 802.11 Wireless Mesh Networks using Two-Layer Mechanism Solution

Moleme et al. [21] proposes a two-layer mechanism for the transportation of real-time video. In this mechanism, rate adaptation is implemented in the data link layer for channel error control, link stability and reliability. In addition, the network layer routing protocol is optimized for congestion control and optimal route selection by using congestion information from the data link layer and link quality metric from the network layer.

The proposed scheme aims at ameliorating the performance of UDP in WMV video streaming applications by improving throughput, packet loss and latency, so the authors in this work try to improve a standard protocol (UDP) to improve the QoS, us you know as we know, affect the operation of a standard protocol is a risk, it may have secondary effects on the proposed solutions

F. An STDMA-Based Framework for QoS Provisioning in Wireless Mesh Network

The framework is based on STDMA scheduling at the MAC layer, which is periodically executed at the network manager to adapt to changes in traffic demand. While scheduling computation is centralized, admission control is performed locally at the wireless backbone nodes, thus reducing signaling.

Leoncini et al. [22] propose two bandwidth distribution and related admission control policies, which are at opposite ends of the network utilization/spatial fairness tradeoff.

G. Conclusion

The link layer is very important to provide QoS for Wireless Mesh Networks. Researchers are focused on specific areas as we have seen. A set of researches focus on mechanisms of allocating resources such as CSMA/CA or TDMA. Other studied queue management, by doing a control admission, and another approach is to use correcting codes.

VI. A PHYSICAL LAYER APPROACHES

The problems of the propagation of radio waves in a cluttered environment with lot of obstacles, are numerous and known. Works on these problems were progressed, but new solutions are regularly found and proposed, as we shall see below.

A. A Study of End to End Video Robust Transmission Via WMN

The Video Transmission over the multi-path fading wireless channel has to overcome the inherent vulnerability of compressed video to the channel errors. To effectively prevent the corruption of video stream and error propagation in spatial and temporal domain, proactive error controls are widely been deployed. A novel video transmission architecture [23] via WMNs is proposed to meet the error robust requirement of wireless video Transmission. This architecture address a strategy of jointing sources coding and channel coding based on H.264 video code standard [23]. By taking the time-varying wireless channel condition and video codec characteristics into account.

B. *Characterizing the End-to-End Throughput in WMN Using Multiple Directional Antennas*

In WMN backbone, the throughput is mainly limited by 2 factors: the ingress/egress congestion in gateway and link interference caused by simultaneous transmissions. Recent study found deploying multiple gateways in WMN is an efficient way to alleviate the ingress/egress bottleneck. Besides, utilizing multiple channels, multiple radio interfaces and directional antenna technology in WMN can greatly alleviate interference problem. In the paper, we propose a practical wireless mesh networks architecture using multi-channels, multi-radios and multiple directional antennas. The end-to-end throughput characters of the proposed WMN are studied based on a network model considering the directional antenna.

A STDMA based centralized link scheduling algorithm is used to ensure proper operation of the backbone transmission. Zhao et al. [24] provide necessary conditions to verify the feasibility of rate vectors in the networks, and use them to derive upper bounds of achievable end-to-end throughput. The approaches are illustrated by simulation examples. The results show that their scheduling algorithm has a better throughput performance compared with scheduling algorithm using greedy method

C. *Distributed Gateway Placement for Cost Minimization in Wireless Mesh Network*

XiaoHua et al. [25] study the problem of gateway placement for cost minimization (GPCM) in two-dimensional wireless mesh networks. They are given a set of mesh routers; assume they have identical transmission range r, represented by unit transmission disks around them.

A router may be selected as a gateway at certain placing cost. A router is served by a gateway if and only if the gateway is within its transmission range. The goal of this work is to select a set of mesh routers as gateways to serve the rest routers with minimum overall cost. This problem is NP-hard. According to the authors, no distributed algorithm with a constant approximation ratio has been given before. Their algorithms greatly improve the best approximation ratios.

D. *Gateways and Performance of WMN*

Gateway has fixed bandwidth to be shared by all the clients for communication. It causes reduction in per client throughput as the number of clients is increasing and thus may lead to overall performance degradation. Associating clients to gateway is a crucial point in deciding performance as is gateway placement, routing and scheduling at the gateway. Associating nodes to a single nearest gateway causes reduction in capacity of WMN and unfairness amongst the nodes. Clients can be associated to multiple gateways. WMN are dynamically self-organizing and self-healing and this imposes even more responsibility on gateways. Having multiple gateways in clustered WMN can improve performance significantly.

E. *conclusion*

The solutions studied in the physical layer, generally focused on:

- The use of smart antennas, directed by our needs, to a particular neighboring node
- Reduction of rate of errors due to transmission
- Use of several gateways instead of one, to balance the load across the network
- The use of novel encoding methods, use of MIMO and use of different frequency of transmission at the same time, by the mobile stations, improve de rate of transmission

VII. GLOBAL CONCLUSION

This paper summarize the challenges in QoS provisioning for Wireless Mesh Networks (WMNs). We reach at the obvious conclusion that if we want to optimize network resources WMN to ensure QOS, the most effective way is to combine the most effective solutions in the three layers together.

In terms of routing, we think the approach of clustering is the most interesting and in another paper, we present our proposal of clustering routing algorithm, with a presentation and discussion of several simulations.

Regarding the solutions of Link layer, changing the CSMA/CA protocol in IEEE 802.11 is not recommended. The link layer provides various solutions for improving the QoS as queue management, error control, etc so we recommend instead, the use of a control admission algorithm, in addition to existed mechanisms of QoS provided in the standard, thus we limit the non-interoperability with equipment already in use.

The use of MIMO (Multiple Input Multiple Output) is already used by AP to increase the speed significantly; also the use of smart antennas is a good option to limit interferences.

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QoS-based Channel and Radio Assignment Algorithm for Mesh Cognitive Radio Networks intended for HealthCare

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***Abstract*— Smart homes monitoring for patient healthcare is an emerging research area. Monitoring smart homes locally at large scale requires a lot of infrastructure deployment which is not a cost effective solution. Thus the recent advancement in the cloud computing and introduction of cognitive radio's provides a new direction to the smart homes monitoring. Thus in future all the data monitoring and analysis at large scale will be on cloud using cognitive radios. Cognitive radios utilize radio spectrum opportunistically without purchasing their license. Therefore, efficient routing and quality of service based channel selection and radio assignment are most challenging issues in the deployment of this technology for remote smart homes monitoring. In this paper, we proposed a novel channel selection and radio assignment scheme for multi-radio multi-channel multi-hop mesh cognitive networks with the objectives of minimizing overall network interference and minimum interference with the primary users. Channel and radio assignment in such networks is a NP-hard problem. Therefore, integer linear programming model is presented and heuristic solution for susceptibility and capacity aware channel selection and radio assignment is proposed. Furthermore, collaborative channel utilization and local healing Scheme is also presented. Our proposed algorithms maintain highly quality of service based stable routes with the overall reduction of network interference.**

Keywords- Multipath routing; Susceptibility and capacity aware channel assignment; Multi-hop mesh cognitive networks; local healing

I. INTRODUCTION

In medical applications collecting patient's related information's are crucial for taking timely treatments and providing other emergency services. In the last few years patient health care has been improved using Smart Homes Monitoring Systems (SHMS). In SHMS the patient related information's are exchanged using modern telecommunication technologies which enable the medical and emergency teams to take timely decision to save the patient's lives [1]. In the past few years, Wireless Mesh Networks (WMN's) turn into a very prominent form of networking and being used for providing many interesting services such as multicast video delivery, content sharing and sensor network backhaul [2]. Moreover, many patients' monitoring and healthcare applications are also relay on this form of networking due to amazing characteristics such as self organization, self haling and self management. WMN has a lot of advantages like large coverage area, low operation and deployment cost and improved reliability and robustness [3] this idea was first introduced by a Victor Pierobon in 1995 [4]. Figure 1 shows SHM using multi-hop mesh cognitive networks.

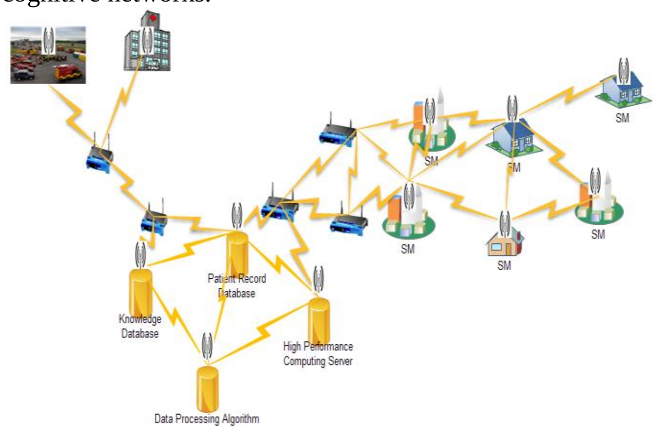

Figure 1. Multi-hop Mesh Cognitive Networking of SM's.

Cognitive Radio (CR) introduced by Joseph Mitola III in 1999 to improve the utilization of radio spectrum is evolves as future networking technology [5]. Recent measurements show that around 70% to 80% of assigned spectrum is being wasted in U.S [6]. Mesh nodes equipped with multiple cognitive radios can be viewed as a novel approach for improving the bandwidth scarcity of mesh networks by efficiently utilizing the white spaces and performing concurrent transmission [7]. Currently, cognitive radios equipped mesh networking is being considered for critical and Quality of Service (QoS) demanding health care applications, where stability of communication paths and reliability of contents delivery are major concern as well these are most critical issues in Cognitive Radio Networks (CRN's).

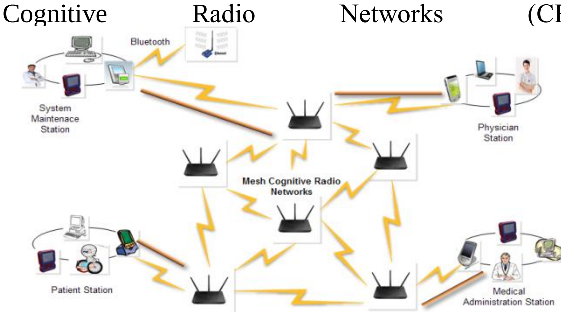

Figure 2. Use of Mesh Cognitive in HealthCare Applications.

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Figure 2 shows another use of cognitive mesh networking for patient health care and medical applications. Figure 3 show the importance of channel and radio assignment for healthcare and remote monitoring applications. All such applications required routing for exchange of information therefore, connected, stable and interference free routes are being demanded. All these can be achieved by efficient channel and radio assignment.

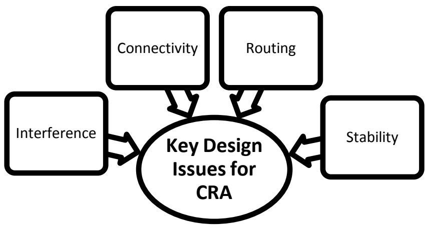

Figure 3. Significance of Channel Assignment.

To the best of our knowledge, available routing proposals for the Mesh Cognitive Radio Networks (MCRNs) select free available channels without considering their susceptibility as well as radios are being selected without proper analysis of their workload. Therefore, an efficient channel and radio assignment mechanism is still an open issue to increase the overall network performance. In this paper, we have presented a new metric that considered the best availability of channel before selection as well as we also considered the utilization of available radio's before their assignment.

The organization of the rest of the paper is as follows: In Section 2, we have presented the current state-of-the-art and our motivation. In section 3, we have presented problem statement, assumptions and system model. In section 4, we have shown derivation and calculation of our selected parameters. In section 5, we presented the Integer Linear Programming (ILP) modeling of channel and radio assignment and our proposed algorithm is presented in section 6. Conclusion and future work are discussed in section 7.

II. LITERATURE REVIEW

Multi-radio MCRN's are more powerful and flexible than Single-radio CRN. Therefore, algorithms designing for Multi-radio MCRN's are substantially more challenging than that for ordinary Single-radio CRN.

Ramachandran et al. [8] calculated interference estimation based on the packet capturing and based on that scheme they purposed channel assignment for mesh networks. Dai et al. [9] presented a channel assignment algorithm for CRN based on SINR. The channel is selected based on the SINR values and then assigned to the communicating nodes. Junior et al. in [10] presented a common control channel based distributed channel assignment algorithm for single radio cognitive networks. Kim et al. in [2] Proposed Urban-X a channel assignment for MCRN operating is ISM band. They use primary node activities and workload as important parameters in their algorithm. Wang et al. in [11] proposed a new multipath routing and spectrum access (MRSA) framework for multi-radio mesh networks assuming cognitive radio (CR) environments. The proposed framework seeks to establish multiple paths that maximize "spectrum wise" disjointedness to minimize contention and interference among links.

It is clear from the current state-of-the-art that the mostly algorithms are focusing on reducing the interferences with the primary user and other co-located users which is the primary objective of the CRN but none of them considering the reliability and stability of available channel set which is primary need of critical applications such as healthcare. Per packet channel switching degrades overall network performance as well as causes long delays in communication which is not affordable in such crucial and QoS demanding applications [12]. Our algorithm mainly focuses on reliability of available and capacity of available channels as well as we considered the workload of available radios.

III. PROBLEM STATEMENT

The channel assignment problem for Multi-hop Multi-radio Mesh Cognitive Networks (M^3CN's) is described as follows: Given a M^3CN with each mesh node equipped with multiple cognitive radios and each node has an option of selecting multiple licensed channels for its communication. The objective of our channel and radio assignment scheme is to select best channels and radios those meets the QoS demand of critical applications for each flow with minimum inter and intra flow interference as well as minimum interference with the primary users. To achieve this objective, we proposed susceptibility and capacity aware channel and radio assignment scheme.

A. Assumptions

Following are assumptions of our system:

- Common Control Channel (CCC) is available for sharing network information's.
- Each cognitive node has the capability of sensing and determining the arrivals and utilization time of licensed channels.

B. Network Model

We are considering that our MCRN is operating under the heterogeneous licensed channels where each node is equipped with multiple cognitive radios. We modeled our network using undirected graph $G = (V, E)$where $V = \{v_1, v_2, \dots . v_n\}$ is set of cognitive nodes and $E = \{e_1, e_2 \dots e_n\}$is set of vertices. $I = \{i_1, i_2, \dots . i_n\}$ is a set of global available channels and each node have a subset of this global set. $Pr = \{Pr_1, Pr_2, \dots . Pr_n\}$ is a global set of primary nodes operating on licensed channels and any subset of this set is operating in any particular vicinity. Each mesh node is equipped with R radios $R = \{R_1, R_2, \dots . R_k\}$ is set of available cognitive radios.

IV. PARAMETERS DERIVATION AND CALCULATION

Our channel and radio assignment algorithm is mainly based on two important parameters known as susceptibility and capacity. These two parameters show characteristics of communication channels in term of reliability of available channels and amount/speed of data delivery over the channels.

A. Susceptibility

Means that how much a channel changes due to the cause of some force or some parameter changing's. In CRN primary user is one of the parameter that's causes the change in licensed channel availability. As we are concentrating on rate of change of channel due to primary user arrivals therefore we will select a channel with less susceptibility value for successful transmission over a stable path to maximize the network performance.

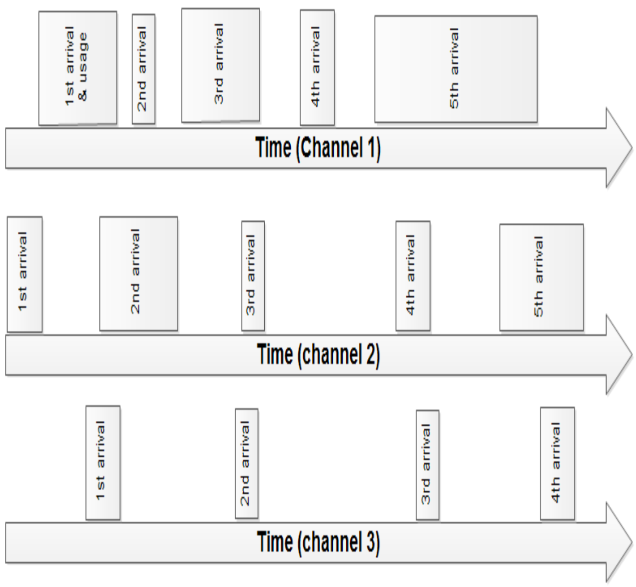

Figure 4. Primary user activity.

In the above Fig 4 $\mathbf{A_1}$, $\mathbf{A_2}$, $\mathbf{A_3}$.... $\mathbf{A_n}$ are the arrivals of primary user on any licensed channel. We are considering a scenario in which no of primary user arrivals as well as utilization time during each arrival is random. First we calculate the total utilization of any licensed channel by its primary user. This calculation is based on following values:

1- Total scanning time of a channel
2- Total number of arrivals
3- Total utilization time during each arrival.

$$CU = \frac{A_1 + A_2 + A_3 + \dots\dots + A_n}{total\ scanning\ time\ of\ a\ channel} \times 100 \qquad (1)$$

Where CU is average Channel Utilization. Above equation (1) gives us the total utilization of a channel, our objective is to find the susceptibility on the basics of channel utilization. Then we will tag each channel based on its susceptibility value and select a most reliable and durable channel from the poll of available channels.

$$Channel\ Susceptibility = \frac{TF\ time\ of\ a\ channel \times 100}{(TU\ time\ of\ channel \times TNA) + TF\ time\ of\ channel} \qquad (2)$$

Where ***TF*** is Total Free, ***TU*** is Total Usage and ***TNA*** is Total Number of Arrivals.

B. Example Calculations

$\frac{70*100}{30*10+70} = 18.91$ when 10 No. of arrivals, and free space 70%

$\frac{50*100}{50*15+50} = 6.25$ when 15 No. of arrivals and free space 50%

$\frac{80*100}{20*4+80} = 50$ when 4 No. of arrivals and free space 80%

So, each node maintains a pool of free available channels with susceptibility tag. Thus pool of free available channel looks like as follows:

TABLE 1. SUSCEPTIBILITY POOL.

Available Channels	Susceptibility Value
C_1	18.91
C_2	6.25
C_3	50

C. Channel capacity

Channel capacity is one of the primary criteria for QoS demanding applications where channel over the selected path ensures this demand [13]. CRN's are heterogeneous in term of channels availability as well as in term of bandwidths. Therefore we are interested to select a channel which is better both in term of susceptibility as well as capacity to fulfill the requirement of applications. The effective capacity of any channel is calculated as follows:

$$\boldsymbol{C^i_{v_i\,v_j} = W_i log_2\left(1 + \frac{P_w}{N_0 W_i} \times d^{-\tau}_{v_i,v_j}\right)} \qquad (3)$$

$\boldsymbol{C^i_{v_i\,v_j}}$ is capacity of channel i between two $nodes\ v_i and\ v_j$, $\boldsymbol{W_i}$ is bandwidth of channel i N_o is power spectral density of noise and $\boldsymbol{d^{-\tau}_{v_i,v_j}}$ is distance between node $\boldsymbol{v_i}$ and $\boldsymbol{v_j}$ with Transmission power $\boldsymbol{P_w}$ and $\boldsymbol{\tau}$ is path fading parameter. Using equation (3) each node calculates the effective capacity on all available channels and further channels are tagged with their effective capacity values. Thus, after associating capacity value against each available channel, our table looks as follows:

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TABLE 2. SUSCEPTIBILITY AND CAPACITY.

Available Channels	Susceptibility Value	Capacity (Mbps)
C_1	18.91	2
C_2	6.25	11
C_3	50	5.5

D. Radio Usage information

We are considering Mesh Cognitive Nodes (MCN's) equipped with multiple radios. As each node is working as router therefore, it's being used for passing many other flows/traffic other than its own traffic. Selecting if radio on any MCN node count a lot as per packet switching of radio causes overall network performance degradation as well causes long delays. Thus for efficient radio utilization and to improve overall network performance each node must add its radio usage information's with the susceptibility and capacity table and use this information for assigning radio for any new flow. Furthermore, operating multiple radios over the same channel cause intra radios interference. Thus our table approach will help to avoid this intra radio interference. After adding radio usage information the table looks like as follows:

TABLE 3. RADIO INFORMATION TABLE (RIT).

Available Radios	Status	Tuned on Channel	Used among No. of Flows
R_1	Idle		0
R_2	Busy	C_1	2
R_3	Idle		0
R_4	Busy	C_3	3

We merge all necessary information's into a single table called Channel Susceptibility Capacity and Radio Information Table (CR^2IT). We will use this CR^2IT table in our SCACRA algorithm. Thus after adding inheriting some use full information from RIT table, CR^2IT looks like as follows:

TABLE 4. CHANNEL SUSCEPTIBILITY CAPACITY RADIO INFORMATION TABLE.

Channel	Susceptibility	Capacity	Radio Usage	Used among No. of Flows
C_1	18.91	2	R_2	2
C_2	6.25	11		0
C_3	50	5.5	R_4	3
C_4	8.91	20		0
C_5	40.12	55		0
C_6	12.40	11		0

V. ILP FORMULATION

In this section, we formulate the Integer Linear Programming (ILP) modeling of radio and channel selection problem. Presented ILP model will help to obtain the optimal results of our said problem. Consider an undirected graph $G = (V, E)$ where $V = \{v_1, v_2, \dots . v_n\}$ is set of cognitive radio node and $E = \{e_1, e_2 \dots e_n\}$ is set of vertices $I = \{i_1, i_2, \dots . i_n\}$ is set of global licensed channels and each cognitive node have subset of this global channel set. C_i is capacity of each channel i. F_{e_j} is flow demand passing on link e_j where e_j is link between two cognitive nodes v_i, v_j operating on channel i. $I' = \{I'_1, I'_2, \dots I'_n\}$ is set of interfering cognitive nodes on channel i. each cognitive node is equipped with multiple radios $R = \{R_1, R_2, \dots . R_k\}$ is set of available radios. $Pr = \{Pr_1, Pr_2, \dots . Pr_n\}$ is set of primary nodes operating in the vicinity of CMN.

A. Decision variables

$$I_{i,v_j}^{Pr} = \begin{cases} \mathbf{1}\ if\ node\ v_j select\ channel\ i\ and\ no\ primary \\ \quad user\ pr\ operating\ on\ it\ in\ its\ vicinity \\ \mathbf{0} \quad\quad otherwise \end{cases}$$

$$R_{e_j}^{r_k} = \begin{cases} \mathbf{1}\ if\ radio\ r_k\ is\ assigned\ to\ link\ e_j\ on\ i \\ \mathbf{0} \quad\quad otherwise \end{cases}$$

$$X_{e_j}^{i,r_k} = \begin{cases} \mathbf{1}\ if\ channel\ i\ is\ assigned\ to\ link\ e_j\ on\ r_k \\ \mathbf{0} \quad\quad otherwise \end{cases}$$

B. Objective Function

$$Max\ \ Z = \sum_{i=1}^{n} . \sum_{e_j \in E}^{1} \sum_{R_k \in E} (F_{e_j} * X_{e_j}^{i,r_k}) * I_{i,v_j}^{Pr} \quad (4)$$

Subject to the following Constraints:

C. Channel availibility Constraint

$$\sum_{\forall pr_l \in P_r} X_{pr_l}^{i,r_p} = 0 \quad (5)$$

Channel is free only when no primary node operating on it.

D. Inter and Intra node Interference Constraint

$$X_{e_j}^{i,r_k} + \sum_{\forall e_k \in I'} X_{e_k}^{i,r_k} \leq 1 \quad (6)$$

At most one mesh cognitive node can operate on free channel from all interfering nodes.

E. Intra flow/radio Interference Constraint

$$X_{e_j}^{i,r_k} + \sum_{\forall r_l \in R} X_{e_k}^{i,r_l} \leq 1 \qquad (7)$$

At any mesh cognitive node at most one radio can operate on any channel at a time.

F. Radio Interfaces Constraint

$$\sum_{\forall r_l \in R} X_{v_i}^{i,r_l} \leq \mathrm{R}_{\mathrm{v_i}} \qquad (8)$$

$$\forall\, \mathrm{v_i} \in V$$

$$where\ \mathrm{R}_{\mathrm{v_i}} \text{ are available radios on node } \mathrm{v_i}$$

Any cognitive node cannot use more than the available interfaces.

G. Channel Constraint

$$\sum_{\forall v_i \in V} X_{v_i}^{i,r_l} \leq \mathrm{I}_{\mathrm{v_i}} \qquad (9)$$

$$\forall\, \mathrm{v_i} \in V\ \&$$
$$\forall\, \mathrm{R}_{\mathrm{v_i}} \in R$$

$$where\ \mathrm{I}_{\mathrm{v_i}} \text{ are available radios on node } \mathrm{v_i}$$

Any mesh cognitive node cannot use more than the available channels or vice vera a channel cannot be assigned if it is not available.

H. Channel Capacity Constraint

$$\mathrm{F}_{\mathrm{e_j}} * \mathrm{X}_{\mathrm{e_j}}^{\mathrm{i,r_k}} \leq \mathrm{C_i} \qquad (10)$$

$$\forall\, \mathrm{v_i} \in V\ \&\ \forall\, \mathrm{i} \in I$$

Mesh cognitive node cannot transmit traffic/flow demand more than the available capacity of the channel.

I. Flow preservation Constraint

$$\sum_{\forall \mathrm{v_i} \epsilon \mathrm{V}} \mathrm{F}_{\mathrm{v_i,v_j}} * \mathrm{X}_{\mathrm{v_i,v_j}}^{\mathrm{i,r_k}} = \mathrm{F}_{\mathrm{v_j,v_k}} * \mathrm{X}_{\mathrm{v_j,v_k}}^{\mathrm{i,r_k}} \qquad (11)$$

$$\forall\, \mathrm{v_i} \in V\ except\ source\ and\ destination\ nodes$$

Each mesh cognitive node must pass the amount of traffic it receives.

J. End to End Flow preservation Constraint

$$\mathrm{F}_{\mathrm{S_i}} * \mathrm{X}_{\mathrm{e_j}}^{\mathrm{i,r_k}} = \mathrm{F}_{\mathrm{D_i}} * \mathrm{X}_{\mathrm{e_j}}^{\mathrm{i,r_k}} \qquad (12)$$

$$\forall\, \mathrm{F}\ \&\ \forall\, S_i\ and\ D_i$$

S_i *and* D_i are source and destination nodes respectively

Amount of data at destination mesh node must be equal the amount of data send by source node.

K. Non Negativity Constraint

$$I_{i,v_j}^{Pr} \geq 0, R_{e_j}^{r_k} \geq 0\ and\ X_{e_j}^{i,r_k} \geq 0 \qquad (13)$$

VI. Proposed Algorithm

In this section, we presented our proposed heuristic algorithm that select best options of channels and radios along a selected path. We are assuming best paths are selected based on any criteria like minimum hop count etc.$Path = \{v_1, v_2, \dots .\, v_3\}$ is a set of selected intermediate mesh cognitive nodes. Before presenting radio and channel selection algorithm we first present collaborative channel utilization and Local healing algorithm for mesh cognitive nodes.

A. Collaborative Channel Utilization and Local Healing Scheme (CCULHS) for Mesh Cognitive Nodes

----

1. All nodes share their CR^2IT information's on Common Control Channel (CCC) with its 1-Hop neighbors periodically or triggered this event when there are some updates in its local CR^2IT.
2. Each node update its table after receiving CR^2IT information's from its 1-Hop neighbors and mark those channel unavailable which are already being used by its 1-Hop neighbor.
3. Each node mark the channel unavailable as primary user is detected on the channel and unicast the new table information with its communicating nodes over CCC.
4. Each effected node selects some other suitable channel locally based on CR^2IT information.
5. Transmeter node tune its Tx on newly selected channel and inform the receiving node about this newly selected channel on CCC.
6. Receving node also tune its Rx and Tx radios accordingly and update its CR^2IT.

C is a set of common channels for path that are used by neither primary node nor any 1-hop MCN. But channels can be already tuned on some other radio on the same MCN. In the following algorithm, we discussed major cases of channel and radios selection and assignment and further sub cases will be considered in the detail while implementing the algorithm. If radio is not idle then tuning already our new channel cause more delay therefore we are giving priority to the channel which is already tuned and we are considering fair scheduling in our algorithm.

B. Susceptibility and Capacity Aware Channel and Radio Assignment (SCACRA) Algorithm

----

```
While (Path! =Null) {
  For each (channel available on all nodes)
    Compute C on path
    While ([vi,vj] ϵ Path) {
     Case 1: both radios and channels are idle {
```

```
6.            If (Rvi = idle && Rvj = idle) {
7.        //Selecting best channel for pair of radios
8.                Compute free channel with less
                  Susceptibility and high Bandwidth
9.            OR
10.               Compute free channel with less
                  Susceptibility and good Bandwidth
11.           OR
12.               Compute free channel with average
                  Susceptibility and High Bandwidth
13.           OR
14.               Compute free channel with average
                  Susceptibility and Average Bandwidth
15.             } end if
16.           } end Case1:
17.       Case 2: One radio and one channel is idle {
18.               If ((Rvi = idle && Rvj ≠ idle) || (Rvi
                      ≠ idle   && Rvj =idle)) {
19.                   Repeat step 11 to 17
20.           OR
21.               Compute used channel with less usage
                  Ratio, less Susceptibility and good
                  Bandwidth and select that already
                  Tuned radio as no idle radio
22.           OR
23.               Compute used channel with average
                  Usage ratio, average Susceptibility and
                  average bandwidth and select that already
                  tuned radio as non idle radio
24.             } end if
25.           } end Case2:
26.       Case 3: Both radio and channels are not idle{
27.         If (Rvi ≠ idle && Rvj ≠ idle) {
28.             Repeat step 11 to 17
29.             OR
30.                 Compute used channels and radios with
                    less usage ratio, less- Susceptibility and
                    good bandwidth and select these
                    channels and radios
31.               OR
32.                 Compute used channels and radios with
                    average usage ratio, average
                    Susceptibility average good bandwidth
                    and select these channels and radios
33.             } end if
34.           } end Case2:
35.         } End While
36.       } End For
37.     } end while
```

VII. Conclusion and Future Work

We proposed a novel susceptibility and capacity aware channel and radio assignment algorithms for MCRN's indented for QoS based traffics like multimedia traffic for healthcare. Susceptibility plays a vital role in reliable channel assignment while capacity ensures the QoS need of, QoS demanding applications. In our future work, we will study the detail analysis of our proposed algorithm with optimal solution which can be obtained from our presented ILP and with some other available algorithms.

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Energy Saving For Wireless Mesh Network

State of the art

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Abstract— **Energy consumption of communication systems is becoming a fundamental issue and among all the sectors, wireless access networks are largely responsible for the increase in consumption. With this increasing demand for energy in wireless field related with the increase in carbon dioxide levels in the environment produced by wireless devices in the idle mode, it is very essential to develop the technology that reduce energy consumption. In this context, Wireless Mesh Networks (WMNs) are commonly considered as the most suitable architecture because of their versatility that allows flexible configurations. Different studies have proposed number of protocols in different layers of TCP/IP model to enhance transmission of data. Very few of these protocols envisage node energy. This paper mainly focuses on classification layer of the largest existing approaches dedicated to energy conservation.**

Keywords-WMN; 802.11s; Energy consumption; TCP/IP layers, Topology control; Power control; Sleep.

I. INTRODUCTION

As various wireless networks evolve into the next generation to provide better services, a key technology, wireless mesh networks (WMNs) has emerged recently [1, 2]. A WMN is dynamically self-organized and self-configured, with the nodes in the network automatically establishing and maintaining mesh connectivity among themselves. The components of the IEEE 802.11s mesh architecture comprise of the following as shown in Fig. 1 [3]. A mesh point (MP) is a node that has also mesh routing capabilities. Mesh points that also have capability to act as access points are called mesh access points (MAPs). IEEE 802.11 mobile clients are called stations (STA) that do not have mesh capabilities and can connect to MAPs to send their data. An MP that is connected to the wired network is called a mesh portal (MPP) or gateway which enables the integration of WMNs with various existing wireless networks such as cellular systems, wireless sensor networks, wireless-fidelity (Wi-Fi) [4] systems, worldwide inter-operability for microwave access (WiMAX) [5].

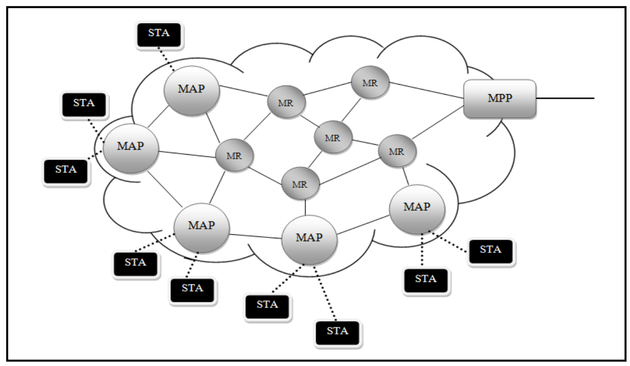

Figure 1. Network architecture of Wireless Mesh Network

Energy consumption is increasing at an exponential rate with heavy growth in the number of access devices. Power management for networks from a perspective that has recently begun to receive attention is targeting the conservation of energy for operating and environmental reasons [6]. Different studies [6, 7] have proposed a rethinking of the way networks are built and operated so that not only costs and performance are taken into account but also their energy consumption and carbon footprint. Significant additional power savings may result by incorporating low-power strategies into the design of network protocols used for data communication.

To reduce energy lost, there are researches that addressed the mechanisms of the Physical Layer to promote energy conservation [9, 10, 12, 13 and 14]. Others work in Data Link Layer is based on IEEE 802.11 standard [15, 16, 17, 18 and 19] that considers energy efficiency. In the Network Layer, studies [30, 31 and 32] have proposed solutions that provide energy saving by using standard routing algorithms with some enhancements.

This paper investigates the state of the art of approaches that reduce energy consumption in different layers of the TCP / IP model. The remainder of this paper is organized as following. Section II explores approaches to energy conservation in Physical Layer. Section III describes different approaches to reduce energy consumption in Data Link Layer. Section IV presents power saving protocols and routing protocols within the Network Layer. Finally, the paper is concluded in Section V.

II. APPROACHES TO ENERGY CONSERVATION IN PHYSICAL LAYER

Physical Layer (PHY) implements a network communication hardware, which transmits and receives messages one bit or symbol at a time. In practice, the PHY receives analog symbols from medium and converts them to digital bits for further processing in the higher layers of protocol stack. The PHY functions available in most transceivers are the selection of a frequency channel and a transmit power, the modulation transmitted and demodulation of received data, symbol synchronization and clock generation for received data [8]. The researches that involve the Physical Layer of WMNs are pointed out in this Section.

A. The LM-SPT (Local Minimum Shortest Path-Tree)

LM-SPT is a fully scalable power-efficient localized distributed topology control algorithm [9], proposed to effectively construct for a meshed backbone network of access points. The approach taken in this work is to construct an overlay graph topology of the WMN this concept is based on information of the local neighborhood that is confined to one hop from the logical visible neighborhood for calculating the minimum power transmission. The LM-SPT algorithm is shown to lead desirable features as reduced physical node degree, increased throughput, increased network lifetime and maintenance of connectivity by varying the transmission power at each node. The main contribution of this work consists in the ability of the algorithm to balance energy efficiency and throughput in WMNs and without loss of connectivity. In this approach Aron et al.[9] proposed to calculate minimum transmission power and require only an optimal value to maintain an optimal connectivity and decrease the interference and collision which save energy and achieve a good throughput.

B. CNN (Critical Number of Neighbors)

Santi [10] used CNN refers to the minimum number of neighbors that should be maintained by each node in order for the network to be asymptotically connected. This approach to maintain connectivity is adopted for use in the proposed scheme because only knowledge of the network size is required to determine the CNN. This information can be easily obtained from a proactive routing protocol such as OLSR [11]. The CNN may also result in heterogeneous transceiver power outputs, potentially maximizing power savings and interference gains. The CNN is also less affected by the distribution and position of the network nodes and there is no need to assume a GPS enabled router. It’s also increases gradually with network size and is thus able to tolerate delays in the propagation of topology updates and network size (if a proactive routing protocol is used). Thus, maintaining connectivity via a CNN will reduce human intervention (if a proactive routing protocol is employed).

The same idea like Aron et al. [9] approach, Santi [10] proposed to calculate minimum number of neighbors that should be maintained to be connected to conserve energy.

C. Minimum-energy topology

Aron et al. [12], considered the problem of topology control in a hybrid WMN of heterogeneous and presented a localized distributed topology control which pointed to calculate the optimal transmission power to maintain connectivity and reduce the transmission power to cover only nearest neighbors and save energy and extend lifetimes of the networks. In this work, the main objective is to generate a minimum-energy topology G graph. Taking an arbitrary node $u \in V$ in the network G, a three phased topology control algorithm that runs in each node. In the first stage, node *u* broadcasts a “hello” message using its full power, $P^{max}{}_{u}$. The nodes that receive the “hello” message form the set of accessible neighborhood of node *u*. The “hello” message contains the id of u, the location information of *u*, (x (u), y (u)) and the value of the $P^{max}{}_{u}$. After there exist a weighted directed graph topology G, $u \in V$. Node *u* has knowledge of the edge weights and path weights, where path weight of a directed path. Finally, in this phase, node *u* determines its own transmission power and the powers on the accessible edges of all the nodes in the accessible neighborhood. Node *u* takes as its power, the largest one-hop edge weight among the edges obtained in the minimum-energy local topology view G, after node u adopts its minimum-energy level; it propagates this minimum power value to the other neighbors in the accessible neighborhood with the current Transmission power. Aron et al. [12] developed a minimum-energy distributed topology control that ensures a reduction in the amount of energy consumed per node during transmissions and without loss of connectivity.

D. PlainTC

Mudali et al. [13] investigate the feasibility of power control in a popular WMN backbone device and design and evaluate an autonomous, light-weight TC scheme called PlainTC. Two main approaches may be used in this regard, either maintaining the Critical Transmission Range (CTR) or the Critical Neighbor Number (CNN). In this work, Mudali et al. [13] presented a TC scheme for a WMN backbone comprising of commercially available Linksys WRT54GL routers (which are popular WMN backbone devices). The proposed scheme is designed to maintain network connectivity by relying on data collected by a proactive routing protocol. Three types of information can be collected and used as the basis of a TC scheme: location information, direction information and neighbor information. The Linksys WRT54GL device contains neither a GPS nor the native ability to determine the relative direction of incoming and outgoing transmissions. The device does however possess the ability to collect low-quality, neighbor-based information by inspecting the routing table built by the proactive routing protocol being employed. Determining the logical node degree is easier because the number of HELLO messages received from unique sources can be determined if a reactive routing protocol is employed. If a proactive routing protocol is employed, then the routing table can be inspected for the number of one-hop (or n-hop) neighbors. The approach proposed by Mudali et al. [13], is designed for a specific device (Linksys WRT54GL) and it contains a GPS to define the direction. Unfortunately, generally the devices are not specific and they are not equipped with a GPS generally.

E. Virtual WLAN

Coskun et al. [14], proposed the switching scheme which aims to powering on the minimum number of devices (or the combination of devices that consume the least energy) that can jointly provide full coverage and enough capacity. Basically, this approach corresponds to having a minimum set of devices that provide coverage and an additional set of devices that are powered on to provide additional capacity when needed. By consolidating hardware, some hardware can be put in low-power mode and energy consumption can be reduced, saving the difference in energy consumption per low-power node when compared to an active node and adding the amount of energy consumed by hosting more networking processes just on fewer network nodes. Depending on the type of device, different amounts can be saved. Using virtual 802.11 interfaces to connect to multiple networks simultaneously, instead of using multiple network interface cards, enables savings in energy costs, minimizes the physical space, and provides the capability to build large and small wireless mesh networks.

Summary

Topology control algorithms have largely been proven to be one way of achieving energy efficiency in MWNs. The main goal of a topology control algorithm is to select appropriate logical neighbors of a node (from a given physical topology network) according to some specified rules (average node degree, throughput, energy consume, network lifetimes). Each node should be able to apply the rules to adjust its transmission power accordingly so that only the necessary logical neighbors are covered. Several contributions have been tailored towards studying power control problems in energy-constrained conventional IEEE 802.11 wireless network standards; little attention has been drawn to the power control problems in WMNs.

Control of topology and control of power transmission are a good ideas, simple but very effective for saving energy, while keeping maximum connectivity and the extending of network lifetime. Some of these studies are summarized in the previous Section. Another trend in research is the mechanisms of the Data Link Layer that promote energy conservation will be present in the next Section.

III. APPROACHES TO ENERGY CONSERVATION IN DATA LINK LAYER

In the previous section, we showed approaches that conserve energy in Physical Layer. We now discuss some of the key issues relating to the implementation of power saving at MAC Layer sub layer of Data Link Layer, which provide a fair mechanism to share access to medium among other nodes. The MAC sub layer determines how and when to utilize PHY functions. Hence, MAC plays a key role in the maximization of node’s energy efficiency. We first briefly review power saving in conventional IEEE 802.11and discussion of recent work that has started to address them.

A. PSM (Power Saving Mode) IEEE 802.11 Protocol

The MAC layer specification in IEEE 802.11 [15], defines two diverse power management modes a station can operate in one of them: active mode and Power Saving Mode (PSM). In active mode, a station is fully powered and is able to exchange frames at any time. While in Power Saving mode, a station is permitted to be in one of two different power states, either in awake state or doze state. An AP in a wireless network observes the mode of each station. A station must first inform its AP about changing its power management mode using Power Management bits within the Frame Control field of the frame used as a power saving request. A station should not enter PSM before it receives an acknowledgement from the AP. During the association procedure, a station informs the AP about its listen interval, which is used to indicate a period of time for which a station in PSM may choose to sleep. Its aim is to reduce energy consumption in conventional IEEE 802.11 standard.

The IEEE 802.11 standard defines power saving for clients devices, by allowing the nodes to switch between the Awake and Doze states. But the standard does not provide mechanism for placing APs into power saving mode and requires that the access point be continuously powered, and this requirement can lead to lost energy.

B. APSD (Automatic Power Save Delivery)

Various enhancements to the above scheme have been included in some of the follow-on standards. For example, IEEE 802.11e defines Automatic Power Save Delivery (APSD) [16]. This includes both contention-based operation (referred to as EDCA) and a polling-based option (called HCCA). In the latter case, the AP functions as a hybrid coordinator (HC), and defines periodic service intervals that allow the synchronous delivery of traffic using Scheduled Automatic Power Save Delivery (S-APSD). In the former case the unscheduled APSD (U-APSD) mechanism permits the station to initiate communication activity by transmitting trigger frames on the uplink in EDCA contention mode. These mechanisms provide for improved flexibility and power saving compared to the original procedures.

C. PSMP (Power Save MultiPoll)

IEEE 802.11n has introduced further enhancements to the U-APSD and S-APSD protocols, referred to as power

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save multipoll (PSMP) [17]. As in its predecessors, there are scheduled (i.e., S-PSMP) and unscheduled (i.e., U-PSMP) versions. S-PSMP provides tighter control over the AP/station timeline by having the AP define a PSMP sequence that includes scheduled times for downlink and uplink transmissions. The ability to do this allows (non-AP) stations to remain in Doze mode during the times when other stations are scheduled to be using the channel and reduces AP/station interaction overheads. U-PSMP is similar to U-APSD in that it supports both triggered and delivery enabled modes.

D. NAV (Network Allocation Vector) And NAM (Network Allocation Map)

The AP uses network allocation vector blocking to prevent channel access to the AP when it is in Doze mode [18]. In conventional IEEE 802.11, a NAV is used at each station to implement a virtual carrier sense mechanism and to block stations from transmitting in cases where the channel has been reserved for some other purpose.

The IEEE 802.11 NAV mechanism is generalized, and a power saving AP includes a network allocation map (NAM) in its beacon broadcasts [19]. The NAM specifies periods of time within the super frame when the AP is unavailable, and during these periods the AP is assumed to be inactive and conserving power.

E. PAMAS (Power-aware Multi Access Protocol with Signaling)

Singh et al. [20], proposed to conserve battery energy by turning off nodes not transmitting or not receiving. It is a combination of original MAC protocol [21], and using a separate channel for a busy signal. By using the busy signal, the terminals are able to determine when and how long they should turn off their radio interfaces. In this protocol, if a node has no packet to transmit, then it should turn off its radio interface if one of its neighboring nodes begins transmitting. Similarly, if at least one neighboring node transmits and another receives, the node should also turn off power because it cannot transmit or receive packets (even if its transmission queue is not empty). This approach uses a separate channel for a busy signal. Each node listens to channel to see when it becomes free to transmit (idle-listening). So it leads to important energy consumption.

F. STEM (Sparse Topology and Energy Management)

Schurgers et al. [22], used a separate control channel to avoid clock synchronization required by IEEE 802.11 PSM. STEM is based on asynchronous beacon packets in a second control channel set to wake receivers. After finishing a transmission, the node turns off its radio interfaces in the data channel. STEM does not provide mechanisms to indicate the status of energy management of a node. Instead, the power management state is only maintained on a database by linking the nodes participating in data communication. Therefore, it is possible that a third source node experiences a significant delay to wake up a receiver node, while the receiver is already awake to the recent communication with other nodes. In this approach Schurgers et al. [22] have used a separate control channel to send packets, asynchronous beacon receivers to wake up. Then the use of these control packets (control overhead) can achieve crucial consumption of energy.

G. S-MAC

S-MAC [23] is an energy efficient MAC protocol for wireless sensor networks. Unlike PAMAS, S-MAC uses the model of periodic listen and sleep to reduce energy consumption by avoiding listening to empty. However, this requires synchronization between neighboring nodes. Latency is increased since a sender must wait for the receiver that it is wake up before starting transmission. But SMAC uses synchronization to form virtual groups of nodes on the same list of sleep. This technique coordinates the nodes to minimize additional latency. In [23], nodes lose some of their energies during the exchange by diffusion of SYNC packets.

H. Admission Control in Power Constrained OFDM/TDMA

Niyato and Hossain [24] proposed an analytical model is developed to investigate the packet-level and the connection-level performances as well as the energy-efficiency in a solar-powered wireless mesh network using OFDM/TDMA transmission. The energy-saving mechanism is implemented through a sleep and wakeup process and is integrated with a round-robin scheduling and an admission control mechanism in the mesh routers. Without an admission control mechanism at a mesh router, packet-level performances as well as the energy saving performances may degrade. Again, if a mesh router spends too much time in the sleep mode, packet-level performances will degrade.

I. Virtualization of NICs

Al-Hazmi and Hermann [25], suggest one of the possible ways to save energy is to shutdown some of the APs, which serve a specific area of interest, if the number of the served stations are decreased in off-peak hours (e.g. at night, weekend, holidays). This could lead to the fact that some locations in the interested area are not covered, and stations located within these locations will not have connections. These can get connectivity by using Network coverage extension/ Relaying capability. In addition to the energy saved by shutting down some APs, NIC virtualization plays a role in reducing energy consumption. But the usage of multiple network interface cards (NICs) demands higher cost, large physical space and more energy consumption.

J. LEACH(Low-Energy Adaptive clustering Hierarchy)

LEACH is scheduled MAC protocol with clustered topology [26]. The nodes organize themselves into local clusters with one node acting as the local cluster head. The cluster heads are chosen randomly according to a specific algorithm based election a probability function which takes into account various criteria such as energy available nodes. To distribute energy consumption evenly, LEACH propose to rotate cluster heads randomly. Each node determines a cluster to associate with by choosing the cluster head that requires minimum communication energy. Once all the nodes are organized into clusters each cluster head creates a schedule for the nodes in the cluster. This allows that each cluster member node can switch to sleep mode at all times except during it transmit time; thus, minimizing its energy consumption. The disadvantage of this protocol [26] is that some nodes operate much more than other nodes and especially the Cluster Head the disadvantage is that these nodes die much faster than other.

Summary

The power saving protocols of MAC sublayer presented in this section is summarized in this Table I.

TABLE I. SUMMARY OF MAC PROTOCOLS

Protocol	Network	Topology	Channel	Synchronization	Contribution
Admission Control in Power	802.11s	Flat	1	No	a round-robin scheduling and sleep/wakeup mechanism
APSD	802.11e	Flat	1	Yes	Active/sleep schedules
LAECH	802.15.4	Clustered	1	Yes	Low energy clustering
NAM	802.11	Flat	1	Yes	Map of active/sleep period
NAV	802.11	Flat	1	Yes	Active/sleep with blockage of transmission when channel is reserved
PAMAS	Ad hoc	Flat	2	No	Wake up radio scheme
PSM	802.11	Flat	1	Yes	Active/sleep period
PSMP	802.11n	Flat	2	Yes	Active/sleep schedules with reducing overheads
SMAC	802.15.4	Flat	1	Yes	Active/sleep schedules
STEM	802.11	Flat	2	NO	Wake up radio with periodic sleep
Virtualization of NIC	802.11	Flat	1	Yes	NIC virtualization

Different mechanisms of MAC sub layer have been presented that allow substantial energy savings in this Section. We have noted that a large majority of work in Mac layer, was based on the proposal of the 802.11 standard, in this case the protocol PSM (Power saving mode) and extended it to improve the functioning. The next Section we will discuss approaches that conserves energy in the Network Layer.

IV. APPROACHES TO ENERGY CONSERVATION IN NETWORK LAYER

Different technique of power saving for multi-hop ad hoc wireless networks that reduces energy consumption have been proposed without diminishing of the capacity or connectivity of the network. As WMNs share many common features with ad hoc networks. Thus, the approaches of energy conservation for ad hoc networks can usually be applied to WMNs. In the Network Layer, power management can benefit from information on the topology; we find essentially the following approaches:

A. *The CDS (Connected Dominating Set)*

The CSD use information of neighborhood or topology to determine the set of nodes which form a connected dominating set (CDS) for the network where all nodes are either a member of the CDS or a direct neighbor of at least one member [27]. Nodes in the CDS are considered the pivotal routing and remain active all the time in order to maintain global connectivity. All other nodes can choose to sleep if necessary.

B. *The SPAN*

SPAN is distributed algorithm, each node in the network running Span makes periodic, local decisions on whether to sleep or stay awake as a coordinator and participates in the forwarding backbone topology [28]. Each node decides to be a coordinator may have two criterions. The first is selection of the nodes with the higher energy to be a coordinator. The second criterion is the value that a node adds to the overall network connectivity. A node connecting more nodes will be more likely to be chosen as coordinator. Span uses broadcast messages to discover and react to changes in the network topology. Finally span integrates with 802.11 power saving mode nicely, non-coordinate can still receive packets when operating in power saving mode. This algorithm can be applied to WLAN mesh network with changes in selection of coordinator in the criterion of energy for example we can choose the access points which are connected with power in the place of those are powered with battery.

C. *The GAF*

The GAF scheme of Xu et al. [29] has similar goals to Span. In GAF, nodes use geographic location information to divide area to cover into fixed square grids. The size of each grid stays constant, regardless of node density. Nodes within a grid switch between sleeping and listening, with the guarantee that one node in each grid stays up to route packets.

One main disadvantage of the three previous approaches [27, 28 and 29] is that it is inherently dependent on node density for energy savings. The basic premise is that there are enough nodes that only a small number of them are needed at any one time. In low density networks, almost no power can be saved using these approaches because almost every node must stay active. Another main disadvantage of these approaches is the overhead required to maintain an effective subset. Since nodes are mobile, the subset must be continually updated in order to provide complete coverage. Even if nodes were not mobile, the subset must be rotated in order to avoid completely draining the resources of a few nodes. Since coordination is required every time the subset changes, this can cause significant amounts of communication traffic which both limits scalability and reduces good-put by cutting into available medium time.

D. The Pulse

The Pulse protocol design is centered on a flood we refer to as a pulse, which is periodically sent at a fixed pulse interval [30]. This pulse flood originates from infrastructure access nodes (pulse sources) and propagates through the entire component of the network. This rhythmic pulse serves two functions simultaneously. It serves as the primary routing mechanism by periodically updating each node in the networks route to the nearest pulse source. Each node tracks the best route to the pulse source by remembering only the node from which it received a flood packet with the lowest metric. If a node needs to send and receive packets, it responds to the flood with a reservation packet. This reservation packet is sent to the pulse source. The reservation packet contains the address of the node making the reservation, and is used to setup reverse routes at all nodes on the path between the pulse source and the sending node. A node that does not send or forward a reservation packet will have no packet forwarding responsibilities until the next pulse occurs, it may place its radio in sleep mode until the next pulse period begins. This node deactivation is what allows the Pulse protocol to conserve power. This protocol [30] has significant disadvantages in the routing information that is essentially the problem of flooding packets and the problem of Overlap delay or it can result in a significant consumption of energy.

E. EMM-DSR protocol

Bouyedou et al. [31], suggest a new mechanism that allows making a trade-off between energy efficiency and the shortness of a selected path for forwarding data packets. In other word, this mechanism tries to minimize the energy consumption and, at the same time, maintain a good end-to-end delay and throughput performance. The solution proposed by Bouyedou et al. consists in extending the Max-Min algorithm to support the cited trade-off. Thus, they incorporate this extension, among other options, to the existing on-demand dynamic source routing protocol (DSR), and the resultant version takes the name of EMM-DSR (Extended Max-Min DSR).

F. Power-Aware Routing

Lin et al. [32], present a power-aware routing algorithm for wireless networks with renewable energy sources. The proposed algorithm is shown to be asymptotically optimal when compared to the full knowledge case. No information is assumed regarding the arrival process and it is assumed that the node has full knowledge of the energy it will receive until the next renewal point by looking at previous data. The proposed routing algorithm uses a composite cost metric that includes power for transmission and reception, replenishment rate, and residual energy. The work also includes non-uniform energy replenishment rates and introduces a battery energy threshold scheme to decrease overhead.

G. The green-clustering

The green-clustering algorithm was developed to enable the central controller in a WLAN to make certain decisions to power on and off portions of it based on certain pre-defined criteria like deployment, location of access points, and locally derived information. Hence, this algorithm was designed with respect to the centralized network infrastructure and its devices [33]. The basic idea was that if access points are close enough in the cluster, a single one would fulfill the needs of users, even those in the vicinity of other APs in the same cluster. This clustering concept was designed with respect to large organizations with high-density WLANs because access points are placed very close to each other to provide overlapping coverage and high bandwidth.

Summary

The discussed routing protocols are summarized and classified in Table II. As routing protocols may use hybrid techniques to achieve their intended target application, some of the protocols are classified to several categories.

Mobility support is evaluated according to the amount of the nodes that can move and the effort required for route reconstruction.

TABLE II. SUMMARY OF ROUTING PROTOCOLS

Routing Protocol	Network	Topology	Classification	Mobility
CDS	Ad hoc	Flat	Node centric routing	---
EMM-DSR	Ad hoc	Flat	Node centric	---
GAF	Ad hoc	Grid	Location based	Partial
Green-clustering	WLAN infrastructure	Clustered	Node centric	---
Power-Aware routing	Multi-hop Wireless	Flat	Cost field based	Partial
Pulse	multi-hop wireless infrastructure	Tree	Cost field based	---
SPAN	Ad hoc	Grid	Location based	Partial

In the network layer, we think that the tendency of clustering is a good approach because it has already proven itself in the MANET as shown in the large numbers of items.

V. CONCLUSION

Reducing power consumption can be achieved on a larger scale by introducing intelligence into the network infrastructure at various levels by employing different kinds of algorithms. This research tends to discuss the best designs for maximum efficiency in terms of power while retaining the best user experience. This paper has reviewed recent work on energy saving in networks WMN, who treated both routing algorithms energy saver, the mechanisms of energy conservation in the MAC layer and finally some topology control methods and the means developed to put in to sleep some routers at certain times. After studying of these works, we reached some conclusions. First, if we want to optimize the problem of energy conservation in WMN, we can intervene on the three lower layers of the OSI model, trying to combine the advantages of the proposed solutions in the state of the art in each layer using the proposal most advantageous in terms of energy savings. In terms of routing, we think that the tendency of clustering is a good approach because it has already proven itself in the MANET as shown in the large numbers of items. We have noted that a large majority of work in Mac layer, was based on the proposal of the 802.11 standard, in this case the protocol PSM (Power saving mode) and extended it to improve the functioning. The works done in the physical layer, all have either used the notion of CNN (Critical Number of Neighbors), or CTR (Critical Transmitting Range), to control the topology of WMN network, in order to optimize consumption of energy. Another trend plays on optimizing the transmission power of nodes, which must be sufficient, and never maximal to keep connectivity without interferences. So we can try to verify if the use of these three ideas together can improve the performance of network, and also saving power, with simulation in future work.

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