Methodology of Dynamic Architectural Adaptation for Ad hoc Networks Operating in Disturbed Environment

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Abstract— **Wireless networks and particularly ad hoc networks, are gaining in speed and capacity. These advances open the way to their use in emergent, increasingly complex applications. Such networks have to operate in disturbed environments where disturbances, mainly caused by fading and interferences, primarily originate by the physical layer. Congestions associated with environment-specific disturbances caused by complex applications, such as emergency and disaster applications, are the second source of disturbance. Such networks must guarantee a QoS (Quality of Service) management to their associated applications, a task that is possible only by minimizing the transmission delay and maximizing the packets delivery ratio. The conventional network architecture used for TCP/IP model shows degradations of performance, especially when the networks operate in environments with physical layer disturbances. This paper presents a study based on the routing performance of ad hoc networks operating in disturbed environment. Simulation results are presented and analyzed to illustrate limitations of the conventional ad hoc network architecture. The methodology of a network architectural design based on cross-layer architecture using a multi-criteria decision making process for quality enhancement is also presented. This work enabled us to highlight a new direction for the communication architecture of cognitive vehicular networks operating under disturbed environment. This direction consists of considering a dynamic reconfiguration of the communication architecture according to the network environment behaviour. Thus, it will allow either the traditional architecture or the cross layer architecture based on autonomous components.**

Keywords- ad hoc networks; ant colony optimization algorithm; adaptive network communication architecture; cross-layer architecture; multi-criteria decision making.

I. INTRODUCTION

Wireless networks, including ad hoc networks, are among emergent telecommunication technologies operating in environments that can cause link failures and degradation of QoS (Quality of Service) in their associated applications. Despite the advances of such technologies, such as large band for G3 and G4 (third and fourth generations of mobile standards and technology), there is still a risk of performance degradation. This risk is especially significant for constrained services such as those used for real-time or near real-time applications. The correlation between physical layer phenomena of ad hoc networks and constraints related to complex applications that involve close nodes and rapid changes in topology make the behaviour of ad hoc network very complex and hard to predict [1][2][3][4]. The effect of this correlation is the guarantee of only the minimum required QoS (Quality of Service). This paper presents an analysis of conventional network architectures operating in disturbed environment. It offers a model for the cross-layer concept that makes it possible to: 1) enhance the network performance by sharing information between non adjacent layers and, 2) take benefits of real-time notifications of channels events representing new states that may have an impact on the performance of network protocols, which also include routing protocols.

Section 2 presents the application context of emergent telecommunication technologies defined by a challenged environment. Section 3 presents a state-of-the-art network communication architecture. A case study on the application of a routing protocol based on Ant Colony Optimisation (ACO) algorithm within conventional network communication architecture is presented in Section 4. Section 5 presents a design methodology for ad hoc networks with a cross-layer architecture based on a multi-criteria decision making model designed to operate in disturbed environment and to guarantees temporal constraints. A conclusion and future directions are presented in Section 6.

II. CHALLENGED ENVIRONMENT OF AD HOC NETWORKS

Numerous studies investigating the challenging environment of communication networks focus on the behavior of their physical layer [5]. For this reason, a good understanding of physical layer will define suitable

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processing in network management and offer the possibility to avoid problems that directly relate to the network QoS. Wireless networks have made remarkable advances and today, they seem to have unlimited capacities. Based on such advances in communication networks, a range of complex applications have been developed, many of which have significant QoS constraints. A realistic observation of networks environments and their physical layer performance makes it possible to detect inadequacies that lead to packet losses and to an increase in the transmission delay for wireless networks.

A. *Interference in the wireless environment*

It is important for wireless networks, especially for ad hoc networks, to define suitable access layer protocols that will minimize, if not avoid, packet collisions due to simultaneous transmissions. Ad hoc networks also require error protocols that counter frequent interference to radio transmissions and deal with the variable network topology of their network nodes. The very complex space geometry of the ad hoc network environment and various obstacles that may be encountered by the radio signals (buildings, bridges and tunnels, etc.) contribute to raising the level of interference. Various phenomena have a direct impact on wireless signal propagation. These include fading of the transmitted signal and multi-path propagation caused by physical phenomena such as refraction, diffraction and reflection. Research on these phenomena and their impact on network quality relies heavily on mathematical models used to represent signal propagation in a realistic manner [5][6][7].

B. *Review of propagation models for wireless networks*

Propagation models are used to simulate the attenuation of wireless signals in a particular environment. Generally, propagation models compute the power of the signal at the receiver as a function of the power of the signal at the transmitter. Depending on the features of a particular environment, one of three main propagation models may be used: free-space loss model, two-ray ground model and shadowing model. Most of the published results in the field of ad hoc wireless routing and broadcasting are based on free-space or two-ray ground propagation models, which are simplistic and idealistic. Indeed, these models are usually unable to capture the spatio-temporal variations of the signal power at the receiver. Therefore, a probabilistic model is more suitable for our study context designed to depict an environment that experiences dynamic events. The shadowing model defined in [8][9] can be used for more realistic propagation models.

The average large scale path loss for an arbitrary Transmitter-Receiver (T-R) separation is expressed in [8] as a function of distance by using a path loss exponent, n. The following equation expresses the average path loss PL (d) for a transmitter and receiver with separation d with d_0 as the reference distance.

$$PL(\mathrm{dB}) = PL(d_0) + 10\,n\log\left(\frac{d}{d_0}\right) + X_{\sigma}$$

Xσ is a zero-mean Gaussian distributed random variable with standard deviation *σ*. An important feature of the shadowing model is its ability to simulate a wide range of environments in which fading and interferences are determined by simply adjusting the value of n.

III. BACKGROUND

In the context of wired networks, layered structures proved to be reliable for usage in numerous high speed communication technologies such as ATM (Asynchronous Transfer Mode) based on SONET (Synchronous Optical Network). Because of the behavior of their physical layer and the impact of the degradation of this behavior on the upper layers, wireless networks have entirely different requirements. Among studies carried out on performance problems in wireless and ad hoc networks, two categories of research activities can be identified. Advances on communication services in the context of TCP/IP communication architecture, is still considered for services innovations in addition to the new architectural design based on the concept of cross-layer.

A. *Advances in communication protocols based on TCP/IP*

Recent research activities on ad hoc networks have made important contributions to accessing the link layer. The result is the ability to minimize the number of collisions of the access link and to optimize the network resources as a spreading spectrum [10]. Other advances in protocols are in the domain of routing protocols. Various approaches, such as metaheuristics [11][12], have been taken to study the adaptive protocols for QoS optimisation.

The main difficulty of these communication architectures is the variation of delay between degradations in the physical layer and reactions in the upper layers.

B. *Architectural design of cross-layer communication*

Research activities on cross-layer architecture have been mainly focused on cognitive networks, which originate in cognitive radio [13]. Adaptation to changes represents an important topic for these networks. This category of research activities focuses on increasing the network performance. Literature on this research topic states potential advantages and direct impacts of the physical layer

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on operations of the nonadjacent high layers such as link layer, network layer and transport layer.

Researchers have attempted to face these important challenges. One of the proposed solutions is based on a cross-layer architecture, which identifies three interaction categories [14]:

- Direct communication between layers, based on variables of a layer visible to the others in runtime. Internal states of the layers have to be managed for this category.
- Sharing of a database between the layers: In addition to the shared database access, a research topic here is the design of interactions between the different layers.
- Elimination of stack structure: The components of communication architecture are autonomous. This category offers a great flexibility but represents a great challenge compared to the well-known organisation of protocols. Numerous research activities have studies cross-layer designs. In [15][16]. In cross-layer communication architectures, it is easier to define a network that has the knowledge of its environment. This is a characteristic that constitutes an important factor for ad hoc networks. In the meantime, a suitable architecture cannot be defined without the knowledge of related applications and their QoS. In Section IV, we present a case study based on the TCP/IP architecture that provides more information about network activities and their impact on the network QoS.

IV. CASE STUDY: ROUTING ALGORITHMS ON NETWORK BASED ON TCP/IP ARCHITECTURE

In this section, we discuss our case study of the application of metaheuristics inspired by the ACO (Ant Colony Optimisation) algorithm extension adapted to mobile ad hoc networks (AntHocNet) [17]. The case study addresses routing problems in a VANET (Vehicular Ad hoc Network) [18], a network that is gaining importance especially in the context of Intelligent Transportation Systems (ITS). VANET is an ad hoc network composed of vehicles with communication capacities and characterized by their mobility model. To address potential issues in the physical layer and the consequences for network performance, we employ the cross-layer concept. Before going into detail on our case study, we present an overview of VANET and the cross-layer concept.

A. Introduction to vehicular internetworking

Wireless networks comprise different categories of networks, such as the Mobile Ad hoc Network (MANET). MANETs are self-configuring ad hoc networks based on mobile routers and VANET (Vehicular Ad hoc Network). In a VANET network, communications may take place between vehicles (vehicle to vehicle) or between vehicles and roadside nodes. Important technological advances in VANET networks have led to the development of a variety of complex applications for ITS such as disaster management. Complex applications must meet QoS with a focus on temporal constraints to manage emergencies on the roads.

B. The concept of cross-layer architecture

The cross-layer concept is based on the principle of layered protocols which constitutes the foundation of the classical architecture of network communication. In the new generation of communication networks, namely cognitive and autonomous networks [14], communication is allowed between nonadjacent layers. This will give rise to a situation where changes on any particular layer can directly affect the quality and the operation of another layer of the hierarchy or affect various aspects of network management such as performance, faults and security. Thus, during the design of a network with cross-layer architecture and according to chosen interaction category, it is necessary to identify new relations between layers and specific processing requirements such as notification of events .

C. Routing protocol based on AntHocNet

AntHocNet is a hybrid algorithm that uses reactive and proactive mechanisms in order to discover routes. The AntHocNet algorithm defined in [17], was adopted in our case study. We also introduced a few modifications to address particular time constraint problems in complex applications. AntHocNet works in four phases: route setup, route maintenance, data routing and route repair.

- Route setup: At the beginning of each communication session between a source node and a destination node, the algorithm creates a special packet called *reactive-forward ant packet* which simulates an *exploration ant*. The *reactive-forward ant* packet is broadcasted at the source and along the network until it reaches the destination node. At the destination, the *forward ant packet* is discarded and a *backward ant packet* is created. The *backward ant* packet will follow the route taken by the *reactive-forward ant* in reverse and will set up a route to the destination at each intermediate route including the source node.

- Route maintenance: The aim pursued in the phase of route maintenance is to either keep the existing routes or to find new routes to the destination. To do this, the source node periodically generates a special packet called *proactive-forward ant* packet which is transmitted to the destination through a random neighbour. The *proactive-forward ant* packet follows its route along the network until it reaches the destination. At the destination node, the *proactive-forward ant* is converted into a *backward ant* packet which, as in the phase of route setup will follow the reverse route and update the routing tables of the intermediate nodes.

- Data routing: The phases of route setup and route maintenance make it possible to find a set of routes to the destination. The phase of data routing consists of choosing one path from this set.

- Route repair: In AntHocNet, each node tries to maintain an updated view of its immediate neighbors at each moment, in order to detect link failures as quickly as possible and before they can lead to transmission errors and packet loss. The presence of a neighboring node can be confirmed when a hello message is received, or after any other successful interception or exchange of signals. The disappearance of a neighbor is assumed when such an event has not taken place for a certain amount of time or when a unicast transmission to this neighbor fails. When a failure is detected, the algorithm removes the responsible neighbor from the neighbor list that it maintains. Then, the algorithm checks the presence of a secondary route to the destinations. If no such route is detected, the algorithm informs its direct precursors by means of a special packet called a *link error packet* which contains all the unreachable. The same process is subsequently repeated until all the nodes in the networks are informed of the change.

The main changes we made in the AntHocNet routing protocol related to specific functions and the overall architecture of the algorithm. Our architecture is sequential and for the sake of simplicity, no concurrency is considered in the present implementation, called AntHocNet-1. Figure 1 illustrates the components of our routing algorithm.

Regarding specific functions, instead of the stochastic mechanism used in AntHocNet, we use a greedy forwarding mechanism in the data routing phase. In addition, while the authors of AntHocNet utilize a combination of delay and hop count as a pheromone amount, we use the total end-to-end delay from the current node to the destination in our implementation.

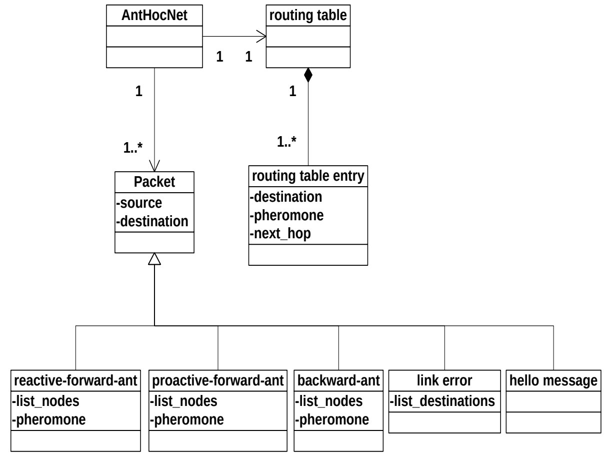

Figure 1: Structure of routing Algorithm AntHocNet-1

D. Experiments on VANET using a Routing Protocol

Our objective is to study the performance of the AntHocNet-1 algorithm in the context of a complex technology such as VANET by considering the temporal constraints as important criteria for assessing network performance. We also propose to study the behavior of this algorithm according to the network architecture by considering traditional (standard) structure TCP/IP with architecture dimensions which would be based on the cross-layer concept.

V. SIMULATION ENVIRONMENT

Experiment environment is made up of two simulators, SUMO (Simulator Urban Mobility), a microscopic road traffic simulator. In order to model the mobility realistically; we selected a tool called MOVE (Mobility model generator for VEhicular networks) [18]. The second simulator is ns-2, used for a communication network simulation [19]. Our experiment environment is illustrated in Figure 2.

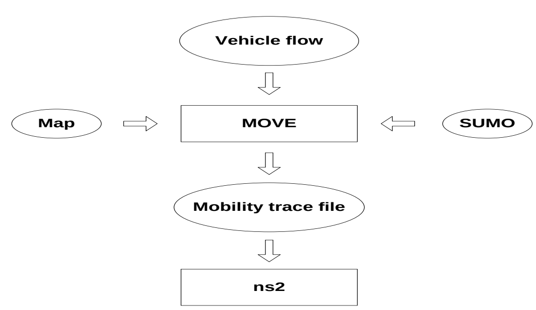

Figure 2: Experiment environment

In our experiment environment, we first identify a set of VANET network features including the topology, the Grid

MAP, vehicles in motion, etc. MOVE uses the SUMO output in form of mobility traces that realistically represent vehicle mobility according to the rules of the road such as traffic light coordination, signs, maximum allowed speed and priorities. MOVE communicates these mobility traces to ns-2. These traces will be used for simulation of VANET network such as the nodes mobility model.

A. Simulation Parameters

In our experiments, the geographical space for VANET is composed of a grid map representing a set of roads. The number of vehicles in our VANET is set to 80. Of these, 50 move according to a model generated by SUMO and the rest are generated randomly and are characterized by setting the periodic packet transmission to a rate of 2 CBR (Constant Bit Rate) packets per second.

The transmission range of the nodes is set to 400 m. We examine two communication protocols having an impact on the network performance: the MAC layer and the network layer. According to the ns-2 implementation based on the *IEEE 802.11/b* standard, the MAC layer is based on the protocol DCF (Distributed Coordination Function), while the physical and network layers will be instantiated. The propagation model for the physical layer is therefore the shadowing model since changes in its parameters will model environment changes and disruptions such as link loss. We use the AntHocNet-1 algorithm as a network protocol in order to study and analyze its performance when faced with environment changes represented by changes in propagation model parameters. We set the simulation duration to 200 s, then run each scenario 10 times. Table 1 shows our simulation parameters.

Simulation parameter	Value
Medium access protocol	DCF
Simulation time	200s
Shadowing model	n=variable, s =4.0
Transmission range	400 m
Transmission power	0.28 mW
CBR	2 packets/s, each packet length is 64 Ko
Number of vehicles	50
Maximum vehicle speed	50 km/h

Table 1. Simulation parameters

In these experiments, specific path losses are defined to represent a degree of environmental disruption. The path loss exponent parameter *n* varies from 2.0 (non-disturbed environment) to 2.1 (disturbed environment) according to the Shadowing model. We evaluate the behavior of AntHocNet-1 through two architectures: the classical architecture based on TCP/IP, in which communication is only between adjacent layers, and the cross-layer architecture, in which communications occur between non-adjacent layers. To test the concept of cross-layer architecture in our simulation, we established the following process: The physical layer monitors, by measurements, the wireless environment in order to detect disruptions. If a disruption, evidenced by changes in the path loss exponent, is detected, the physical layer directly notifies the network layer. In this study, we simulated physical and routing layers interactions by temporal notifications. The AntHocNet-1 protocol reacts to the notifications by executing the phase of route repair. In this experiment we change the frequency of disturbances from every 10 s to every 100 s, while keeping the length of each disturbance constant set to a value equal to 5 s.

Simulation results in terms of end-to-end delay are illustrated in Figure 3.

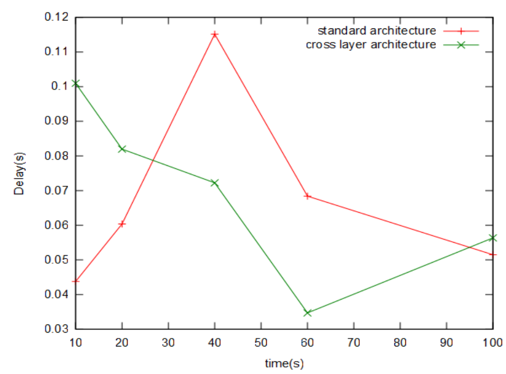

Figure 3: Simulated cross-layer vs. standard architecture behaviors

A. Towards a cross-layer network architecture based on multi-criteria decision making

The results show the impacts of disturbances in the physical layer on the performance of the routing protocol. The tested network uses the traditional communication architecture set up according to the TCP/IP model. It is worth noting that this architecture is based on requests between layers and the delays for reactions especially in a congested network, a situation that causes a loss of communication packets.

In order to support complex communication requirements of applications, the network communication architecture proposed in this study is based on the concept of cross-layer. This section analyzes the consequences of potential side effects caused by significant changes in the frequencies of physical layer.

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B. Cross-layer operating scenarios

The subject of our study has been QoS requirements of complex applications. These requirements can be multicriteria and one of the criteria can consist of real-time constraints. We hence stress the importance of communication between the layers through notifications followed by real-time reactions. Thus, for mobile ad hoc network, significant changes of channel radio must be transmitted immediately after their occurrence to the concerned layers .

According to our previous works [1][20], an increase in the frequencies of environment disturbances events will lead to performance degradations defining networks congestion or systems saturation. These disturbances manifest themselves by a failure to process events within the temporal constraints. The same behaviour is then likely to occur in a mobile ad hoc network tested in this study and illustrated in Figure 3. The network based on cross-layer concept responds to this condition by continuous reconfigurations of its network protocol presented by route maintenance in AntHocNet-1 algorithm and which seems to lead to performance degradation according to disturbances frequency.

C. Methodology of a dynamically reconfigurable architecture

The unpredictable environment behaviour in mobile ad hoc network and the risks of congestions and saturation described previously, make it difficult, if not impossible, to validate the design of the cross-layer architecture in order to guarantee the required QoS. This is even more critical when applications have to deal with dynamic criteria that represent their QoS. Thus, cross-layer architectures presented in section III cannot be used systematically in the context of our study despite their performances observed for some physical layer states compared to the standard communication protocol. We define a methodology of an adaptive architecture design that is more suitable for environment changes. An adaptive architecture faces the problem of experimental identification of parameters for the communications between layers. Thus, parameters such as waiting delays between the occurrence of the events and the reactions of higher layers will be adjusted to the QoS requirements of applications.

We consider learning by reinforcement as a direction to readjust the parameters of communications. This will be possible by using the network management system feedback on the global quality of the network in a given state of the environment and by the usage of parameters for a given architecture configuration. A decision-making process will also be integrated within the reinforcement learning in order to evaluate the network QoS based on a multicriteria objective function to optimise. Finally, this study will consider numerous areas of applications to validate the communication architecture. It also will study its adaptations and the associated dynamic decisions based on different criteria defined by applications requirements.

V. CONCLUSION AND FUTURE DIRECTIONS

This paper presented a realistic context of the application of ad hoc networks and the new requirements for real-time applications. It has presented experiments on a routing protocol based on the Ant Colony Optimisation (ACO) algorithm alternative on a network traditional architecture used for TCP/IP model and a cross-layer concept. The results show performance degradations according to the physical layer perturbations for each architecture model.

Study of the cross-layer concept demonstrates potential advantages of these networks, especially in presence of temporal constraints but not in the case of extreme disturbances. The required architectural adaptations may lead to a cognitive network that represents a promising solution for today's applications, which are mainly based on ad hoc networks. Consequently, suitable network communication architecture is defined by its ability to adapt its parameters and configuration to the changes of the environment network, especially following the notifications of metrics related to the quality of the radio channel along the routes.

This work enabled us to highlight a new direction for the communication architecture of cognitive vehicular networks operating under disturbed environment such as the quality degradation of the radio channel along the routes. This direction consists of considering a dynamic reconfiguration of the communication architecture. Consequently, suitable network communication architecture is defined by its ability to adapt its parameters and configuration either by the traditional architecture or the cross layer architecture based on autonomous components. Reinforcement learning is a suitable approach to identifying on line the best architecture among the traditional TCP/IP architecture that feature waiting times in communication between layers and cross-layer architecture based on non-adjacent layer events notifications.

Validating cross-layer architecture in the context of this study requires realistic applications considering their QoS requirements. Applications for network resource management will be considered for the validation of future approaches. We will also consider simulations based on autonomic components in our future study to examine the communication network architecture based on the cross-layer concept.

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