MAC Protocols and Mobility Management Module for Healthcare Applications Using Wireless Sensor Networks

Muhsin Atto and Chris Guy

University of Reading, Reading, United Kingdom
{kp003919, c.g.guy}@reading.ac.uk

***Abstract*— Using Wireless Sensor Networks (WSNs) in healthcare systems has had a lot of attention in recent years. In much of this research tasks like sensor data processing, health states decision making and emergency message sending are done by a remote server. Many patients with lots of sensor data consume a great deal of communication resources, bring a burden to the remote server and delay the decision time and notification time. A healthcare application for elderly people using WSN has been simulated in this paper. A WSN designed for the proposed healthcare application needs efficient Medium Access Control (MAC) and routing protocols to provide a guarantee for the reliability of the data delivered from the patients to the medical centre. Based on these requirements, the GinMAC protocol including a mobility module has been chosen, to provide the required performance such as reliability for data delivery and energy saving. Simulation results show that this modification to GinMAC can offer the required performance for the proposed healthcare application.**

***Keywords*—WSN;Healthcare Applications; GinMAC; Mobility; Castalia.**

I. Introduction

Wireless Sensor Networks (WSNs) have been widely used in a variety of applications dealing with monitoring, such as healthcare monitoring, environment monitoring, fire detection and so on. A WSN is composed of tiny, battery powered devices, called sensor nodes. The design and implementation of WSNs face several challenges, mainly due to the limited resources and limited capabilities of sensor nodes, such as power and storage. To accomplish their task, sensor nodes are required to communicate with each other and act as intermediate nodes to forward data on behalf of others so that this data can reach the sink, which is responsible for taking the required decision. Different applications using WSNs have different requirements so no generic results can be used [1], [2].

The initial applications supported by WSNs were mostly in environment monitoring, such as temperature monitoring for a specific area, house alarms, and so on. The main objectives in such applications only involved simple data processing. Energy consumption needed to be considered for specific applications, so little attention was taken on data delivery and reliability related issues such as in [1], [3].

WSNs have been extended and their designs have been advanced to support more complex applications, such as security, military, fire detection and health care related issues. In these applications, data delivery and reliability must be taken as important parameters in addition to energy efficiency, because data must be collected from the sources of events and be forwarded to the sink in real time with high reliability, otherwise the application may not fulfil its purpose [4].

In this paper, an implementation of GinMAC [1] including a proposed mobility management module is described and simulated for a healthcare application, where energy saving, delay and reliability for end to end data delivery over multi hop WSNs needs to be considered. Some scenarios are given to simulate GinMAC for the proposed healthcare application, where mobility of nodes and reliability of the data are big issues.

The rest of the paper is structured as follow. Related work and motivations for the paper are given in Sections II and III, respectively. The implementation of GinMAC for both static and mobility applications are described in Section IV. The proposed healthcare application is described in Section V. Simulation scenarios and the required parameters with figures showing the results for GinMAC implementation for the proposed applications are given in Section VI. The simulation results and some discussion is in Section VII. A conclusion and proposals for future work are presented in Section VIII.

II. Related work

Wireless Sensor Networks consist of a set of nodes where each node has a number of sensors with the capability of collecting data about events and sending them back to a Base Station (BS). In order to ensure the successful operation of WSNs, efficient MAC and routing protocols need to be designed. The MAC protocol in a WSN controls the accessing of channels in a network, so the highest number of nodes can share the communication capability, without affecting the integrity of the data delivered to the indicated destination. Due to the wireless communication and insufficient resources and hard challenges in WSN, an efficient MAC protocol is one of the most important factors that needs to be considered before designing any applications, to enhance the life time and improve the performance of the proposed applications [5], [6].

A. MAC Protocols for WSNs

Designing a MAC protocol for WSN is not a simple task, due to the challenging application environments and restrictions, such as energy constraints, latency, data delivery, self-configuration, self-organization and many other challenges in such networks [2]. The main aims of designing MAC protocols are reducing consumed energy, decreasing delay and increasing the reliability of such networks. A major motivation for this work is to design MAC protocols for WSN applications where energy saving, data delivery and latency from node to node in multi hops WSN networks need to be guaranteed. In a wireless sensor network, major energy waste can occur for several reasons, as described in [2], [7], [8]. The first and most important source of consuming energy in WSN is idle listening; this happens when a node is listening to an idle channel to share the medium, and it thinks there is a possibility of receiving or sending packets.

The second reason for the consumption of energy is collisions, due to a high number of sensor nodes deployed in a small area and a large number of control packets. The third reason for wasting energy is overhearing; overhearing occurs when a node listens or overhears a packet, thinking it may be the intended receiver, however, in fact the packet is not for that particular node. Some most important design factors for protocols in WSN that need to be considered while designing and deploying energy efficient MAC protocols for any applications are the following: network topology, type of antenna and clustering related issues [2].

In general, MAC protocols can be divided into two types, which are Time Division Multiple Access (TDMA) protocols and contention based protocols. Each of them has advantages and disadvantages. Schedule based protocols have no collision related problems and are energy efficient protocols, however, scalability in a very dynamic WSN is a big problem for such protocols. Contention based protocols have better performance in terms of scalability in distributed WSNs, however, collisions are a big problem for such protocols.

1) Schedule Based MAC Protocols: In WSNs, to allow sensors to gain access to the shared wireless medium in a cooperative manner, schedule-based MAC protocols have been proposed that regulate access to resources according to a schedule to avoid contention among nodes. Depending upon the medium access technique, the resources could be a time slot, a frequency band or a Code Division Multiple Access (CDMA) code. The main aim of schedule-base MAC protocols is to achieve a high degree of energy conservation to prolong the lifetime of the network. Most of the schedule-based MAC protocols for WSNs use a variant of a TDMA scheme whereby the time available is divided into slots. Using this scheme, a logical frame of N contiguous slots is formed and this logical frame repeats itself in cycles over time. Each sensor node is assigned a set of specific time slots per frame and this set constitutes the schedule according to which the sensor node gains access to the medium and has the right to transmit or receive. This schedule can be either fixed, or constructed on demand, on a per frame basis, by the base-station to reflect the current requirements of sensor nodes and traffic pattern. The nodes must also satisfy the interference constraint, which says that no nodes within two hops of each other may use the same slot [9].

This two hop constraint is needed to avoid the hidden node problem when there is chance this could happen. Energy conservation is achieved by using an on and off mechanism for the sensor radio transceiver [10]. According to the schedule of each sensor node, a sensor alternates between two modes of operation: active mode and sleep mode. A sensor is in active mode when it is its turn to use the assigned time slots within the logical frame to transmit and receive data frames. Outside these sensor assigned time slots, it moves into sleep mode by switching off its radio transceiver.

2) Contention Based MAC Protocols: Contention based MAC protocols are also known as Carrier Sense Multiple Access/Collision Avoidance based protocols (CSMA/CA). These protocols do not pre-allocate resources to individual sensors. Instead, they employ an on-demand channel access mechanism and in this way share a single radio channel among the contending nodes. Simultaneous attempts to access the communications medium, however, results in a collision. Effectively, these protocols try to minimize rather than completely avoid the occurrence of collisions. Traditional networks use Carrier Sense Multiple Access (CSMA) as a medium access mechanism. However, CSMA/CA mechanism gives poor performance in WSNs due to two unique problems: the hidden node problem and the exposed node problem. The hidden node problem is where node A is transmitting to node B and node C, which is out of coverage of A will sense the channel as idle and start packet transmission to node B as well. Consequently, the two packets will collide at node B. In this case CSMA/CA fails to foresee this collision [11]. In the proposed real time applications the main aim is to save energy and improve reliability so a schedule based MAC protocol has been chosen.

B. Design Issues and Challenges for WSN

Due to the limitations and design restrictions of WSN, such as wireless communication and resource limitations, the design of protocols has many challenges, new proposed protocols need to consider these restrictions during their designing and deploying phases. To meet these restrictions, the following important factors and design issues need to be considered for new protocols [3] and [12].

Data Delivery Models: A WSN is an application specific network, so data delivery models need to be designed according to the given application. Some applications need to deliver data from sensor nodes directly toward the sink over a single hop away from the sink, while the others send data over multiple hops between source nodes and a sink. So data delivery models will impact the performance of the new proposed protocols.

Operating Environment: WSNs can be used for different kinds of applications and each of these applications will have a specific requirement. For instance, a WSN used for environment monitoring needs to have specific protocols that can deal with the specific challenges. Moreover, WSNs used in real-time related applications need to have efficient protocols in order to provide the required performance for these applications.

Energy Saving: Due to the limited power capacity associated with each node in a WSN, newly designed protocols must take power consumption related issues as their most important objective. Each node must consume as little power as possible in order to extend the lifetime of the whole network, therefore, the trade-off between energy consumption and data delivery in the WSN are hot topics in recent research studies. Energy can be saved by letting nodes go to sleep when there is no data to sent and received.

Connectivity: Pre-established connections between each pair of nodes in the WSN define the connectivity of the network. WSNs may be densely deployed in an interest area, and there will probably be cases where this connection will have failed and be disconnected. This can happen when some nodes leave the network or die and this means that the topology of the WSN may change very frequently. Therefore, mobility may need to be considered in new proposed protocols.

Hardware Constraints: Typically, nodes in WSN are equipped with small amounts of resources, such as memory, processing capability and power. However, in some applications protocols there is a need to store a large amount of data before forwarding it to the next hop. Because of the limited available memory at each node, that node may not be able to store all the data in its local memory. Hence some techniques need to be designed to reduce the overflow of the data at each node in the network.

Low Node Cost: As a WSN may consist of hundreds or even thousands of nodes, the cost of each individual node must be as low as possible as this will reduce the cost of the whole network.

Scalability and Adaptation: Since the number of nodes in the network may be large and the communication links are prone to fail, and nodes have the ability to join or leave the network, the new protocols need to be scalable and to be able to adapt to any size of network.

Self-Configuring: After nodes are deployed, they need to be able to organize themselves in order to be able to communicate, and when some nodes die and the topology has been changed, it should be possible for them to re-configure themselves without user interaction.

Security and Privacy: Due to the wireless communication between sensors in WSN, it is possible that data may be listened to by unauthorised nodes. Hence the requirements for security and privacy of data needs to be considered when designing applications using WSNs.

Quality of Service (QoS) support: Some applications in WSNs may need to deliver data with specific QoS requirements, for example, delivering data at a required time with bounded latency and reliability. In the proposed healthcare application, the reliability of the delivered data is the most important factor, which needs to be considered. In the following sections, most of the MAC protocols proposed in the literature will be debated when some of the above challenges are considered for the proposed application.

C. Proposed MAC protocols for WSN

Some of the recently proposed MAC protocols such as [7], [2] are discussed in term of their suitability for real time applications, such as military, fire detection or health care related applications. A real time application deals with a hard deadline, so energy is not the only the consideration for the MAC protocol designs. Data delivery and reliability must also be taken into account before designing and deploying the proposed applications. Details of such MAC protocols, with their advantages and disadvantages in terms of energy saving, delay and reliability for data delivery over multi-hops WSNs are discussed in the following sections.

1) Sensor-MAC (S-MAC): This MAC protocol [7] has been designed mainly for WSNs, with energy efficiency as its primary goal. The traditional MAC protocols are not suitable to be used for WSN; they are designed for systems that power on most of the time, because nodes can be powered by recharges, so there is no power limitation. However, nodes in WSN need to be turned off as much as possible to enhance the lifetime of the entire network. S-MAC is based on the 802.15 IEEE standards; it uses the same techniques to share the medium. The S-MAC protocol reduces energy wasting from idle listening, collisions and overhead, using low duty cycle operations for all nodes in a multi hop WSN. It reduces the energy used by nodes in their idle listening time, by putting nodes in sleep mode when there is no need to be active and there is no data to sent and received at the current time.

S-MAC lets nodes periodically sleep, which decreases used energy, but increases end to end delay, because the sender needs to wait until the receiver wakes up to receive the data. In order to reduce this delay, S-MAC uses a new technique called *adaptive listen*, which lets nodes adaptively go to sleep in their listening time when no communications occur, and hence this will reduce long active idle times. In a WSN there may be cases where some nodes have more data than others to send or receive. In such cases, S-MAC uses a message passing technique to divide the long messages into small packets and transmits them in a burst, to avoid having to retransmit a long message again, in the case of failed delivery. Most of the proposed MAC protocols discussed in this paper are based on the S-MAC. Each of these protocols tries to solve problems associated with S-MAC.

S-MAC Techniques for Energy saving and Reducing Delay:

- Duty cycle scheme in multi-hop WSN that reduces energy consumption by nodes in their idle listening time.
- Adaptive listening technique, which greatly reduces the delay occurred during periodic sleeping.
- Using message passing to reduce the energy usage and delay caused by retransmitting after long message failed delivery

- Using Network Allocation Vector (NAV) with RTS and CTS to avoid collision and hidden terminal related problems, when several nodes at the same time need to communicate.
- S-MAC let nodes interfering with each other go to sleep to avoid overhearing, and this saves some energy as well.
- Schedule sleep synchronization, this technique is used by each node in the WSN to organize its schedule table with its neighbours.

Choosing and Maintaining Sleep Scheduling Tables in S-MAC: Each node in the WSN needs to organize and exchange its schedule time with its immediate neighbours before starting to communicate in its allowed time period. There is a schedule table stored at each node in the WSN, including the schedule of its own and for all of its neighbours. Each node in the WSN uses the following cases when obtaining its schedule tables from the network. More details can be found in [2] and [7].

- Each node waits for a fixed time before broadcasting its schedule table to its neighbours. If it does not receive any schedule from its neighbours, it will broadcast its own schedule table.
- If the node hears another schedule before announcing its own schedule, it uses the new one and simply discards its own.
- In the case where a node hears different schedule tables from different nodes, there are two possible ways to deal with this case. The first way is if the node does not have any neighbours, it simply discards its own schedule and follows the new one, while the second way is if the node has already received schedule adaptation from its neighbours, it updates its own table with the new received schedule tables and then broadcasts its own schedule table.

Advantages:

- Using the duty cycling concept, S-MAC saves energy for nodes in WSN.
- Using the adaptive listening concept, S-MAC reduces delays associated with unnecessary waiting times for sleep periods and hence reduces energy consumption.
- Good scalability and topology management.

Disadvantages:

- Fixed period sleeping and waking up is not suitable for real time applications as this may cause huge delays in multi hop networks.
- Does not provide reliability for end to end data delivery.
- S-MAC lets nodes that are interfering go to sleep, and this can cause problems when a path later on goes through one of these nodes, which shows that S-MAC does not support cross layer concepts.
- Due to the need to establish a sleep/wakeup schedule for each node in a WSN, there is an overhead, which will decrease the throughput for data delivery.
- The end to end delay is increased meaning that this protocol can not be applied for real time applications without improvement.

2) Medium Access Control with a Dynamic Duty Cycle (DSMAC): DSMAC [8] has been proposed with the aim of reducing energy wastage and decreasing the delay associated with S-MAC, using a dynamic duty cycle. It achieves a good trade off between energy saving and delay. DSMAC dynamically changes the state of the nodes, for instance, from active to sleep depending on the traffic conditions and level of consumed energy and current delay, without any predefined information. This will save energy and decrease delays associated with S-MAC in an efficient way.

DSMAC uses a synchronizing tables techniques to organize the scheduling time for nodes in the network, to let them know when they need to be asleep or to be active. Each node in the WSN maintains its own schedule table like S-MAC, from already received SYNC packets from its immediate neighbours, then follows and broadcasts its schedule table to its neighbours. In addition, DSMAC keeps a track of an average of energy consumption and latency delay, using scheduling operations related information. DSMAC estimates the current traffic load and then changes cycle dynamically if needed.

Advantages:

- Saving energy using dynamic multiple duty cycling improves S-MAC.
- Decreasing the delays the associated with S-MAC from node to node using wakeup and sleep, changing modes dynamically, depending on the current traffic load and level of the consumed energy.
- Increasing throughput when traffic is high compared with S-MAC.
- Good scalability.

Disadvantages:

- Does not provide reliability for end to end data delivery.
- DSMAC lets nodes that are interfering go to sleep, and this can cause problems when the path goes through one of these nodes. This shows that DSMAC does not support cross layer concepts.
- The need for the dynamic SYNC announcement for each node in the WSN and storing the average of consumed energy and delay, causes an overhead and this will decrease throughput.
- The end to end delay is increased, so DSMAC is not suitable to be used for the proposed application without improvement.

3) An adaptivity Energy -Efficient and Low latency MAC for Data gathering (D-MAC): In WSN most application traffic is represented as a directed tree related topology, which enables the applications to collect data from multiple source nodes, and send to a single sink. In this case, the sink node will be the root and the sensor nodes will be the children. This type of topology can control the traffic in the network compared with flat topologies. Nodes in the selected path can communicate with each other to solve the interfering problems in S-MAC. DMAC is designed to reduce energy and latency associated with S-MAC, more details can be found [2] and [13].

As mentioned before, S-MAC lets nodes that are interfering go to sleep, this will not allow nodes that are two hops away from the current node notify ongoing traffic, and this will introduce extra delay in the case where some of these nodes are selected later on in the path. Therefore, this will cause data forwarding interruption related problems. To solve this problem, D-MAC [13] has been proposed; DMAC utilises a sleep schedule of each node, which is dependent of its depth in the tree. D-MAC adaptively changes the cycle for the nodes according to the current traffic load in a similar way to DSMAC.

D-MAC uses data prediction techniques for data gathering from source nodes toward the sink, in case the traffic is low and the aggregated amount of data needed to be forwarded at intermediate nodes is high. This can be raised when the current duty cycle is unable to handle this transmission. Hence data prediction related approaches will let nodes be active as long as needed. Furthermore, D-MAC uses a More to Send (MTS) technique for the nodes in the multi paths to remain active when one node fails to send a packet to its parent.

Advantages:

- Energy saving using duty cycling technique
- Decreasing delay associated with S-MAC using data gathering and prediction techniques.
- Increasing throughput when traffic is high compared with S-MAC.
- Solving data forwarding interruption problems.
- Delay end to end decreased.

Disadvantages:

- Does not provide reliability for end to end data delivery.
- Suffers from overhead due to having extra SYNC announcement for each level of the traffic, to predict the nodes, which need to be active in WSN later on.
- Does not support cross layer.
- If data needs to be collected from arbitrary nodes, D-MAC may face problems.
- The end to end delay is not guaranteed.

4) Routing Enhanced Duty Cycle MAC (RMAC): RMAC [14] is a MAC protocol that supports a cross layer approach. This protocol has been designed to provide energy efficiency and to reduce delays associated with previous protocols such as S-MAC, DSMAC and D-MAC. RMAC lets nodes in the expected path from source nodes to the sink to go to sleep and intelligently wake up when they need to send or receive data in multi-hop networks. In addition, RMAC achieves significant improvement for the end to end data delivery in a single cycle in multi hops, as it reduces the contention period much more efficiently than S-MAC. Furthermore, RMAC sends a control frame along the path to inform the nodes in the selected path of traffic before the actual data packet is transmitted.

Advantages:

- RMAC saves energy using single duty cycling technique
- Increases throughput where traffic is high, compared to S-MAC.
- Supports a cross layer approach.
- End to end delay is decreased.

Disadvantages:

- Does not provide a guarantee for delay and reliability for end to end data delivery, which means that it is not suitable to be used for the proposed applications.

5) Q-MAC: Data collection for applications in WSN can be divided into three types; event-detection based applications, periodic-sensed-based applications and query-based applications. Each of these applications has its own techniques to deal with collecting data from one or more sensor nodes and sending to the sink. Various MAC protocols have been proposed for each type, with the aim of energy and delay efficiency for the indicated applications [15].

Query-based applications are types of applications where users put their request for data into a query and send this to the specific part of the area where sensor nodes are deployed. These types of applications can improve minimum end to end delay latency with efficient energy usage. When there are no queries in the network, all nodes will save energy by turning off their radios. However, when a query is initiated by a user and it has been sent to the network, scheduling and SYNCH related packets will be broadcast automatically to deal with data communication, depending on the locations of the specified nodes in the query. This will enhance the lifetime of the network, because only part of the network will deal with this data communication, and nodes in the rest of the network will be sleeping.

The main objectives of the Q-MAC [15] protocol are (1)reduce end to end delay by informing the intermediate nodes in advance about ongoing traffic using dynamic scheduling, (2) enhance the lifetime of the entire network by activating only the nodes that need to deal with data communication, which are predefined in the query. Simulation results in [15] concluded that Q-MAC improves latency 80% over S-MAC.

Advantages:

- Q-MAC saves energy using query based techniques.
- Increases throughput when traffic is high, compared to S-MAC.
- End to end delay is decreased using queries based techniques.
- Supports multiple destinations.

Disadvantages:

- Does not provide reliability for end to end data delivery.
- Does not support cross layer.
- End to end delay not guaranteed, and so it is not the right protocol to be used for real time applications.

6) PEDAMACS: PEDAMACS [16] is a MAC protocol based on TDMA, the aim of this protocol is to save energy and to reduce end to end delay for multi hops in WSN. PEDAMACS provides the extension of single hop TDMA to be used in multi-hops TDMA. It uses a high power transmission Access Point (AP) to synchronize the scheduling information of the nodes using one hop away nodes. This means that this protocol needs to use different transmissions to collect data and organizes scheduling information among sensor nodes. It requires an AP which can reach any node in the network which has unlimited amounts of energy. It is the root of the deployed network.

PEDAMACS depends on topology discovery information to organize the nodes using different phases: topology learning, topology collection, scheduling and adjustment. PEDAMACS uses three different transmission ranges: largest transmission, lowest transmission and medium transmission ranges. The AP uses the largest transmission range to broadcast the topology and scheduling information to the network. Sensor nodes use lowest transmission to collect data in the network, and medium transmission is used to discover local topology related information.

PEDAMACS phases PEDAMAC uses the following phases to broadcast the required information to collect data between nodes in the network [16]:

Topology Learning Phase: The AP uses this phase to broadcast topology learning coordination packets to all sensor nodes or other nodes in the network, to organize the scheduling related issues. The topology learning packet contains two time slots, which represent the current, and next times. The current time is for sensor nodes to set their scheduling according to this time, and the next time is the time when nodes need to stop their transmission and wait for the AP to receive a new current and next times. After sensor nodes receive their current and next time, the AP needs to broadcast a tree construction packet. Nodes receive this packet according to their neighbours depth path to the AP. After the tree topology is constructed, nodes need to broadcast their updated scheduling information to the whole network.

Topology Collection Phase: After the AP broadcasts its topology learning phase, topology collection packets need to be broadcast in the next time slot and then each node organizes its local topology using the information in the topology collecting packet. Then they listen to their parents and transmit their local topology using lowest transmission range. In this phase, nodes use CSMA to listen to their parents and to receive next and current times from receiving topology packets.

Scheduling Phase: In order to organize the scheduling tables for all nodes in the network, the AP broadcasts the scheduling packets based on its knowledge of the complete network topology, to set the schedule tables for each node in the network. Each scheduling packet contains the current and next time as in the previous phases, to let nodes organize their times and later on to divide their times into slots depending on the data transmission requirements of each node in the network.

Adjustment Phase: PEDAMACS uses this phase at the end of scheduling phase to complete the topology of the network and to add any other required modifications, such as mobility of nodes and adding new nodes and so on, depending on the given application. The AP broadcasts an adjustment packet to spread the rest of the information using current and next times as done in the above phases using medium transmission range. Nodes need to access this packet to find how to organize their scheduling times with given current and next slot times. The adjustment packet also includes information to let nodes have access to the next adjustment packet, and to send it to the AP in the next time period. This will allow all nodes to be able to reach the AP.

Advantages:

- Energy saving for sending and receiving data in the network.
- Throughput increasing when traffic is high, compared to S-MAC.
- End to end delay guaranteed
- Supports cross layer, such as routing protocols.

Disadvantages:

- No reliability provided, this means that this protocol is not suitable to be used for the proposed application when reliability needs to be guaranteed.

7) E2RMAC: In general, Contention-based MAC protocols have been preferred for WSN over TDMA, because of the need for TDMA synchronization and the unsuitability of TDMA for distributed and dynamically changed topology of the WSN. Most of the proposed contention based MAC protocols for the WSN use adaptive duty cycling protocols and wake up on demand duty cycling techniques, in which different channels with different powers are used to deal with data transmission. E2RMAC [17] is a protocol based on Contention techniques, but which allows for CDMA operations. Its aim is to provide energy efficiency, reliability and bounded latency for data delivery from source nodes to the sink. E2RMAC performs wakeup duty cycling to achieve its goals.

Basic Operations for E2RMAC

- When nodes need to send or receive data, they need to send wakeup tones to the network to wake up the nodes that are expected to share the data communication, after waiting a random time.
- Secondly, all neighbours of the current sender that hear the wake up tone, put their radios into high power mode, to be ready for the data transmission.
- Thirdly, the sender sends a filter packet, which contains the address of the intended destination, and switches its radio to sleep mode, then the receiver receives the filter packet and keeps its radio in the high power mode and makes other neighbours put their radios into sleep mode.
- Finally, the sender sends the data packet to the destination and goes to sleep, then the receiver receives the data, sends back an ACK to the sender and goes to sleep.
- If packets are successfully received by intermediate nodes, they will forward these received packets to the next hop without waiting for back off time, which will reduce overall delay.

Advantages:

- Energy saving using duty cycling techniques.
- Throughput increasing when traffic is high, compared to S-MAC.

- Supports cross layer and solves the problem of data forwarding interruption using routing techniques.

Disadvantages:

- Overhearing may occur, when sender hears an ACK from some intermediate node and it thinks it is the intended receiver.
- E2RMAC uses wake up, filter packet and then data packet to transfer data from source to the sink, which may increase end to end delay in large networks.
- End to end reliability for data delivery is not guaranteed and hence this protocol can not be applied for real time applications when reliability and delay need to be guaranteed.

8) QoSMAC protocol: Quality of Services (QoS) in WSN is to guarantee some specific parameters, which need to be considered when designing for a given application. The QoSMAC [18] protocol is based on TDMA, which can handle routing with medium access. The topology that is used in this protocol is a tree, so in this protocol, nodes need to organize themselves as a tree, where the root is the sink and the leaves are nodes. Data collecting and processing are done among the sensor nodes and go up toward the sink. The services that this protocol aim to achieve are providing guarantees for node to node delay and reliability for the data delivery between source nodes to the base station (sink).

Advantages:

- Energy saving using duty cycling technique
- End to end delay decreases compared to S-MAC.
- Throughput increases when traffic is high, compared to S-MAC.
- Solves the problem of data forwarding interruption using routing techniques.
- Delay and reliability node to node guaranteed

Disadvantages:

- If data needs to be collected from arbitrary nodes, QoS-MAC may face problems.
- The maximum number of nodes is small, so it is not suitable for large WSN networks.
- Delay and reliability end to end are not guaranteed, so this protocol can not be applied for the proposed application where reliability is one of the most important parameters, which needs to be considered.

9) GinMAC: GinMAC [19] is the first MAC protocol that has been proposed to consider reliability for the data delivery in time critical related operations. GinMAC is a tree based MAC protocol and uses different techniques to achieve its goals, such as reliability and timely delivered data, by considering the topology of the environment, which must be known at the deployment phase before running the application. Examples of applications that GinMAC can support are real time applications in WSN, such as fire detection, military, health care related applications, with relatively small number of nodes.

GinMAC is a TDMA based MAC protocol, using low duty cycling to save energy for nodes when they have nothing to send and receive. We conclude that this MAC protocol is the best for energy consumption related issues over the pre discussed MAC protocols in this paper. In order to achieve this performance, GinMAC must be flexible in case the topology changes. In addition, GinMAC must be adaptable for adding or subtracting nodes from or into the network [20], [21].

GinMAC uses three features to deal with data delivery; Off-Line Dimensioning, Exclusive TDMA and Delay Confirm Reliability Control. Off-Line Dimensioning is used to divide the frames into three slots, which are basic, additional, and unused slots. The Basic slot is used for forwarding one message toward the sink within frame size F. The Additional slot is used to improve transmission reliability, and the unused slot is for improving low duty cycling to save energy. GinMAC uses these techniques and slots to improve energy consumption and reliability for data delivered from source nodes toward the sink.

Advantages:

- Energy saving for sending and receiving data in the WSN, using TDMA based techniques
- Throughput increases when traffic is high compared to S-MAC.
- Supports a cross layer approach.
- Supports real time communications.
- End to end timely data delivery and reliability guaranteed, so it is a good start point MAC protocol to be used for the proposed healthcare application with small number of nodes in the WSN.

Disadvantages:

- Supports small number of nodes; the maximum allowed number of nodes is 25.

III. MOTIVATIONS

Most of the recently proposed protocols for WSNs consider either energy saving or reliability for the target applications, none of them have considered both performance metrics at the same time [2]. However, some applications may need to guarantee both energy saving and reliability at the same time, otherwise the applications will not fulfil their purpose. Therefore, in order to provide this, new and very efficient Medium Access Control (MAC) protocols need to be designed. Previous works showed that GinMAC is the only protocol, which can be used for real-time applications to provide the required performances as shown in [4]. The motivations for this paper are the following:

- Design MAC protocols for the proposed healthcare application where the required energy saving, reliability and delay for data delivery need to be considered.
- Design mobility management modules for the proposed healthcare application.
- Adapt GinMAC to add new features to improve its applicability to real-time applications which require mobility, such as healthcare applications as described in [22].
- Simulate a GinMAC implementation including the proposed mobility management module given in [1] for the proposed healthcare application.

IV. MAC protocols for Real-time Applications

It was concluded in [4] that GinMAC is a possible MAC protocol for use in real-time applications, where reliability, energy saving and delay can be guaranteed. Challenges and requirements that need to be considered before designing any MAC protocols for such applications are also described in the same paper. The implementation of GinMAC including a mobility management module is described in this section.

A. Implementation of GinMAC for Real-time Applications

GinMAC [23] is a TDMA based MAC protocol, so energy saving and reliability with bounded delay can be achieved. However, an efficient synchronization and slot allocation algorithm needs to be designed in order to allocate the required slot time for each node in the network and let the radio of the nodes be turned on only in the allocated time. In this case, each node needs enough slots of time to transmit data toward a sink, including control messages, such as messages for slots permission, mobility and topology control related messages. GinMAC has been modified to add new features to improve its applicability to applications, which require mobility, such as healthcare applications. The GinMAC implementation in [23] does not support mobility while this one does. Topology management and time synchronization for GinMAC in this implementation are described below.

1) Slot allocations in GinMAC: GinMAC is a TDMA based protocol and assumes that data is forwarded hop by hop toward a sink using a tree based topology, consisting of n nodes. Time in GinMAC is divided into a fixed length called *Epoch E*, each E is subdivided by $n*k$ time slots so that each node allocates k slots for transmitting data toward its parent until it reaches a sink. Each node is assigned k exclusive slots with four different types; basic slots (*TX,RX*) for data transmitting and receiving, additional slots (*RTX,RRX*) for re transmitting, broadcast slots (*BROD*) for topology control between nodes in the network and unused slots (*U*) for saving energy (if any). More details about how these slots are used can be found in Figure 1.

Additional slots are used only for retransmission to achieve the required reliability of the target applications. These slots are used even in the case when no data is available for transmission, as described in [19]. Unused slots are used for saving energy when data cannot be delivered using basic and additional slots. This implementation for GinMAC does not contain unused slots, but they may be used in the future for increasing the lifetime of the network. Broadcasting slots are used for topology control. Slots for each node need to be allocated according to the defined topology so that the required performance can be achieved.

2) GinMAC Topology Control Management: GinMAC is a tree based WSN topology so that each node transmits its data toward a sink in its allocated slots and sleeps for the rest of the time. The current static topology that is proposed is a WSN with 13 nodes with static slot allocation, each node has enough slots of time to transmit all data from its children and its own, including control messages toward a sink. GinMAC supports mobility for leaf nodes and this will require the design of new topology control and management algorithms to provide connectivity between static and mobile nodes in the network. It is assumed that the BS has adequate power to reach all nodes in the network using down-link slots. However, the sensor nodes cannot always do this because of their limited power supply.

A node added to the network must determine in which slots it must become active before it can transmit or receive data. After a node is switched on, it must first ensure time synchronization with the rest of the nodes in the network. Both control and data messages transmitted in the network can be used to obtain time synchronization. The node continuously listens to overhear a packet from the sink. After overhearing one message, the node knows when the GinMAC frame starts as each message carries information about the slot in which it was transmitted.

As a next step, the node must find its position in the topology, which must stay within the defined topology envelope. For this purpose, the new node listens for packets in all slots. Transmitted data packets from a sink use a header field in which a node that is ready for transmission can find its information and then according to this information start and stop data transmission toward its parent. A node may be configured with a list of valid nodes or clusters that it is allowed to attach to when mobility is supported. This might be necessary to ensure that a node will only attempt to join the network using known good links, as determined by measurements before the deployment to provide the required performance.

3) Synchronization Messages for GinMAC: At the start of each frame, the sink needs to broadcast a synchronization packet which is denoted as *SYNCH* into the network. This packet holds the start time, end time and slot numbers for each node in the network. When nodes receive a SYNCH packet from the network, they will extract their information from the SYNCH packet and then discard it. In this case, CSMA is used by the sink to synchronize nodes in the network and nodes use TDMA to transmit their data to their parents. After nodes receive their slot information from the sink, they need to ask permission for data transmission from their parents. Then, after slots related information has been received by a node, it has to handshake with its parent and then can start to transmit data. After a node uses its allocated slots, it can go to sleep and wake up at the same time in the next frame. Each node in this case will access the channel using their unique start time, so this will avoid any chance of collision with transmissions from other nodes in the network.

GinMAC lets nodes and their parents be active at the same time so that data can be transmitted between them. This time synchronization algorithm is good enough to deliver packets with the required performances for the applications described in Section VI.

The core idea behind this GinMAC implementation is to let nodes sleep as much as possible without effecting data delivery and required maximum delay, and this can only be done using a TDMA based technique. The static topology is

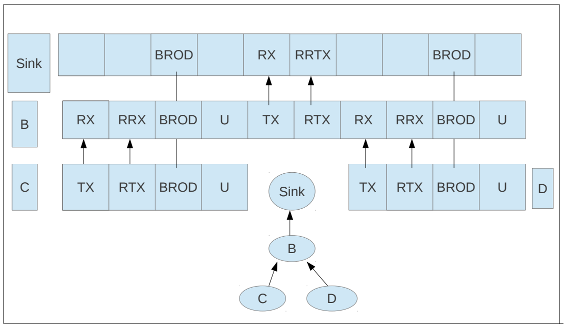

Fig. 1. Slot allocations and Synchronizations for nodes using GinMAC.

designed to let nodes have enough slots to transmit their data and in the rest of the frame go to sleep. The slot allocation and synchronization for GinMAC can be found in the Figure 1.

B. Mobility for Real-time Applications Using GinMAC

A new challenge is posed when mobility needs to be considered in a WSN. In this case topology control, resource management and performance control need to be designed to provide good connectivity between static and mobile nodes in the network and provide the required performance. Mobility and topology control for critical applications using WSNs are described in [24], [25], [26]. The proposed mobility management module in this paper follows the same messages and concepts as in the above papers.

1) Mobility Management Module for GinMAC: There may be cases when moving from one location to another in the network effects the connectivity of the network and then reconfiguration algorithms are needed. In order to support mobility for real-time applications, control messages, which need to be transferred between static and mobile nodes to find a better attachment have been defined. Some of the possible control messages are Advertisement (*ADV*), join (*JOIN*), and join acknowledgement (*JOIN ACK*) messages. Static nodes are formed into *Clusters*.

When nodes in a cluster switch on their radios, they need to send ADV to the network and then wait some time. When mobile nodes receive these ADV messages they will ask to join the network. When a static node receives JOIN messages from the mobile nodes they will send back a JOIN ACK message to let the mobile node know that request to join has been accepted. So using these control messages connectivity between mobile nodes and cluster nodes will be established. In the proposed application only leaf nodes are allowed to be mobile nodes and all other nodes are part of a fixed cluster. The mobility module lets nodes move across a line between mobile nodes and a sink.

Mobile nodes may have more than one cluster they could join, so they have to decide which cluster will be selected for transferring data toward their parents. In this GinMAC implementation, the cluster with maximum Receiver Signal Strength Indicator (RSSI) is considered the best one to be selected for the new attachment. Cluster nodes send ADV including available positions over time and when mobile nodes receive ADV, they compare the RSSI from their current parents to the received RSSI from the current ADV messages. In the case that a new cluster has a better RSSI, mobile nodes need to leave their current parents and attach to this new cluster, which is included in the currently received ADV message. When a new attachment is selected then a join request needs to be sent to that cluster. Upon receiving the JOIN request from a mobile node, JOIN ACK needs to be sent by the selected clusters.

Slots in the each frame need to be updated according to the new attachments. Mobile nodes need to release the first tree position after it is attached to the second tree address, so in this case slots allocated for the new clusters need to be increased and slots allocated for the old clusters need to be decreased. A new algorithm for updating slots is needed for GinMAC to balance allocated slots for nodes according to the different attachments. A new algorithm has been designed to update channel allocation according to new movements and changes in the topology of the network.

2) Move Detection in GinMAC: There are some cases when nodes can move without being detected. For instance, clusters may be unaware of leaving mobile nodes and then will keep space in the channel for that particular node. This will consume more energy and reduce the reliability of the network. There may be cases when clusters are not available for attachment any more without letting mobile nodes know. So an additional two control messages for this new mobility module for the proposed MAC protocol have been used, which are denoted by *KEEPALIVE* and *NODEALIVE*. The *KEEPALIVE* control message is used by clusters to let its currently attached mobile nodes know that this cluster is still available and *NODEALIVE* message is used by mobile nodes to let their attached clusters know that they are still available for attachment. Mobile nodes wait for a specific interval to receive messages from the attached clusters, if they do not receive anything during that interval, a *NODEALIVE* message needs to be sent, to let a cluster know that they still want to use that cluster. If no reply is received then mobile nodes need to search for a new address to make a new attachment.

V. A Proposed Healthcare System

Because of the fast growing numbers of people aged over 80 years old, the cost of medical care is increasing day by day. Recent advances in technology have led to the development of small, intelligent, wearable sensors capable of remotely performing critical health monitoring tasks, and then transmitting the patient's data back to health care centres over the wireless medium. Such health monitoring platforms aim to continuously monitor mobile patients needing permanent surveillance. However, to set up such platforms several issues along the communication chain need to be resolved [27].

The healthcare field is always looking for more efficient ways to provide patients with the best and most comfortable care possible. Providing proper monitoring can be expensive for their family and may force them to move from their homes because living alone will be too much of a risk of their health. It has been assumed, such as in [22], that a WSN could be used to monitor and treat patients remotely, based on data collecting from the body of the patients.

One way to approach this task is to use an application to monitor the health of patients that allow caregiver or relatives to keep watch on the patients health status with much lower cost and without forcing them to move their patients into a unfamiliar environments such as hospitals. Furthermore, these applications can be helpful to the elderly people who suffer from poor memory problems by providing them with advanced features such as helping them to take medicine, locating important objects in their homes and so on [28].

In this paper, an application based on the prototype given in [22] has been used to monitor the healthcare of the patients remotely in their homes where mobility and reliability are the biggest issues. There is a large amount of data to be managed in the proposed application, therefore, an efficient MAC protocol needs to be designed in order to provide the required performance by the proposed application.

Based on the above criteria, the proposed MAC protocol and mobility module given in [1] is used to provide the required performance for this healthcare application. Some simulations have been performed to evaluate the performance of the proposed MAC protocol. Energy saving, delay, reliability and mobility are considered as the most important QoS parameters in this application.

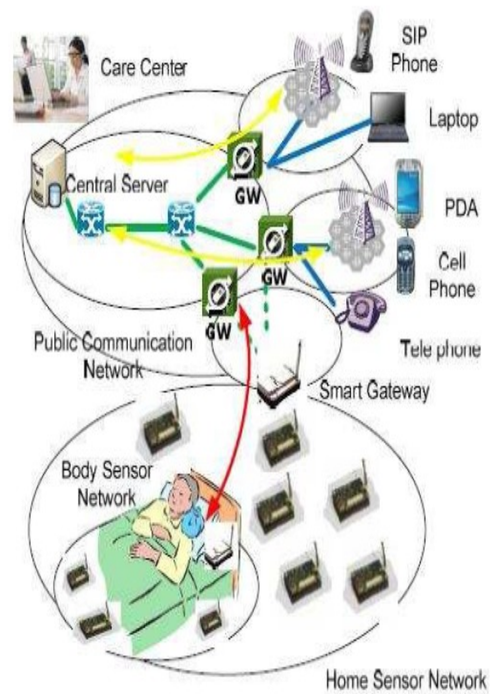

Fig. 2. Structure of the proposed Healthcare Application [22].

A. Structure of the Proposed Application

The proposed healthcare system consists of four different parts as elaborated in [22] and shown in Figure 2. The first part is the home monitoring part where sensor nodes are probed to get multiple sets of data or behaviours, activities, health status using a Body Sensor Network (BSN), and living environment information via a Home Sensor Network (HSN). The HSN is distributed in living room, bedroom, kitchen, bathroom and corridor, to collect the required data. BSN and HSN sensors need to be attached to the body of the patients and to the environment that these patients are living in, without effecting their daily activities.

The second part is the decision part, which is the most important function in the proposed application, because the performance of the whole application depends of the decision made by this part. This part depends on the data received at the BS using both BSN and HSN. The required medical decisions need to be given depending on the data collecting from home, data from body of the patients and the previous status. Hence, the BS is responsible for collecting data from both the HSN and BSN and forwarding to the Health Centre (HC) or caregivers (doctors and relatives). Therefore, the BS needs to be smart enough to deal with data collecting from different parts of the network and to send to the medical centre, which will take the required decisions.

The third part involves care-givers, including doctors or nurses in the hospital and possibly relatives. These are responsible for dealing with the medical report messages (normal or alarm messages), that are sent to them. In the proposed application there should be the possibility for relatives to check the elder's current health status through online web pages using some sort of authentication techniques.

The fourth part is Public Communication Network (PCN) including Internet, GSM/GPRS, Ethernet, and WI-FI. PCN delivers generated messages from BS to care givers to do the required operations.

B. WSN in the Healthcare System

The first part of the proposed healthcare system using WSNs is deployed in a home to monitor and collect data from the home and body of the patients. Each patient is monitored by a WSN divided into two sub networks, which are a BSN and a HSN. A Base Station receives data from both BSN and HSN and then gives commands to the corresponding network.

1) Design of Body Sensor Networks (BSNs) for the proposed Healthcare Application: Sensors for each BSN need to be deployed according to the physical diseases that the system is aimed at monitoring, for example heart rate sensors. More about physical processes and their issues can be found in Section V-D. In the proposed healthcare application only one physical medical parameter is considered for monitoring, which is body temperature. So, the BSN consists of one sensor attached to the body of the patient, data that represents temperature needs to be collected from this sensor and then combined with the sensors in the environment that these patients are living in, such as kitchen, living rooms and so on, and finally sent back to the BS, to take any required medical decisions.

If the proposed application needs to be used for more than one disease, then the BSN needs to be modified to sense data from all parts of the body and send back to a sink. In this Body Area Network (BAN), with several nodes, each node deals with one disease. The biggest challenges in this case is how to combine the BAN with the wider WSN and to combine this with data from the environments that these patients are living in.

In order to provide a comfortable system that in which does not effect the patients daily activities, there will be a lot of challenges, which need to be considered, such as size of sensors that need to be attached on the body of the patients. Each sensor needs to be as small as possible so that it can easily be attached to the body of the patients without affecting their daily activities, whilst still providing the required quality of service and performance.

2) Design of Home Sensor Networks for the Proposed Healthcare Application: HSNs in the WSNs for each patient needs to be designed to monitor the environment that a patient is living in. In this case, each room will have a number of sensors to measure the data needs to be collected and must cooperate with BSNs when the patient is in that room. The collected data then needs to be forwarded to the BS to take the required decisions. An efficient mobility module needs to be designed to provide the required connection between BSNs and HSNs when patients are moving from one room to another.

3) Design of Base Station for the Proposed Healthcare Application: As mentioned before, data from each patient needs to be collected and forwarded to the BS before transferring to the caregivers. Hence, in the proposed application, the BS becomes the core of the healthcare system. Thus, the proposed healthcare application needs a smart BS to deal with data collection from patients, for instance dealing with patient's activities, their behaviours, dealing with the required reports, such as normal and emergency alarms and so on.

In this application, each patient needs to be registered under at least one doctor in the medical centre so that all reports related to this patient can be forwarded to his or her caregivers. In addition, each patient needs to have at least one other contact in case there is an emergency. Therefore, a BS needs to include a data base to store information about all patients in the system including their close relatives and doctors such as names, addresses, phone numbers and so on.

Regular (not emergency) reports about the health status of patients need to be sent to their relatives over time. One way for providing reports for patients to their relatives is using personal web pages for each patient subject to some required authentication process. Two types of reports are provided in the proposed application; regular and healthcare reports. Regular reports record the health status for each patient over time during the application, while health reports show what medical operations and other necessary care needs to be carried out by relatives or doctors within a given time frame.

C. Data Communication in the Proposed Healthcare Application

Based on the required criteria for the proposed healthcare application given in this paper, a GinMAC implementation given in [1] has been used to provide the required performance such as energy saving, delay, reliability and mobility. Some simulation results and conclusions will be given about GinMAC for the proposed healthcare system to demonstrate that GinMAC is a suitable MAC to be used for this application.

D. Designing Physical Process for the Proposed Healthcare Application

Nodes in the simulated system can be fed by the physical process being monitored using three different cases, the first case is feeding nodes with static data. The second case is feeding nodes with different data based on the different sources, where each source can change in time and space. The third case is using a trace file, where nodes are assigned from the trace file. The simulation parameters used in Castalia determines the physical process at a certain time using the equation given in [29].

VI. Simulating GinMAC for the Proposed Healthcare Application

The GinMAC protocol is compared with Time out MAC (TMAC) [30] in terms of performing the required performance for the proposed application. Reliability is considered to be the most important factor, which needs to be guaranteed for this application, but energy consumption, delay and mobility also are measured. A simple scenario, where the number of nodes is low, has been simulated using GinMAC, including the proposed mobility module with different parameters. More details about the simulation parameters and scenarios are given below.

A. Simulation Scenarios and Parameters

Castalia has been used in this work, because of its capabilities for simulating protocols for WSNs based on the real data, as shown in [29]. Both MAC protocols were simulated according to the application requirements given in the following sections, using different sensing intervals. We define sensing interval by Ii = one packets per *i* second, so as it can be seen from the graphs in our simulation results that I1 means nodes sense environment and send data using one packet per second, I2 means nodes sense and send data using one packet per 2 seconds and so on. More details about the topology of the deployed WSN in the proposed healthcare application, MAC protocols and other parameters can be found in Table I.

B. Simulation Application and Measurements

A simple scenario for the proposed healthcare application where all nodes send data towards a sink using different sensing intervals is used.

1) ***Reliability****:* Reliability is considered to be the percentage of packets successfully delivered from source nodes to the sink.

TABLE I
SIMULATION PARAMETERS.

Paremeter	Value
MAC Protocols	GinMAC and TMAC
Network Dimensions(in meters)	90 X 90
Distance Between pair of nodes	25 meters
Simulation Duration	10 minutes
Measurement Metrics	Life time, delay and reliability
Number of Nodes	13
Sensing Intervals (packet per second(s))	1,2,5,10
mobility speed(meters in seconds)	5
mobility interval(in minutes)	1
Advertisement interval (in seconds)	15
MaxLatency (in seconds)	10
MaxColumns	6
Initial Energy(in Joules)	18720
Real Radio	CC2420

*2) **Energy Saving and Lifetime**:* The lifetime of the network is the maximum days that a WSN can survive, whilst spending energy at a given rate. Let total consumed energy by each node be denoted by C joules, initial energy by E joules and current simulation time by T seconds, then the lifetime of given MAC protocols for each node in the network has been calculated as follow:

$$LifeTime(n)(indays) = ((E/C) * T)/86400 \qquad (1)$$

where *86400* is number of seconds in each day and (E/T) is an average of consumed energy in a second by node n. In this way, the life time of the entire network is assumed to be an average of the lifetime for all nodes in the network. It has been assumed that nodes in the proposed healthcare application can be recharged every week.

*3) **Delay Calculation**:* Delay is defined as the difference between the time when each packet is sent from its source node to the time when the same packet is received by its final destination. Delay in real-time applications needs to be measured to ensure that all data is delivered within a bounded delay, i.e., each packet that is delivered after this delay is considered to be lost and will be ignored. All data needs to be collected from the source nodes and then delivered to the sink within a minimum delay.

C. Simulation for Static and Mobility Scenarios

GinMAC and TMAC have been simulated with different sensing intervals as shown in each graph. The WSN topology and the results graphs from running simulation for both static and mobility scenarios are shown below.

VII. SIMULATION RESULTS AND CONCLUSION

Simulation results and discussion for both static and mobility scenarios using GinMAC and TMAC including the proposed mobility module are described below.

1) Packets Delivery and Reliability: It is shown in Figure 4 that GinMAC can offer the applications requirements in term of reliability (as defined in Section VI) using various sensing intervals. GinMAC delivers more than 0.99 of packets

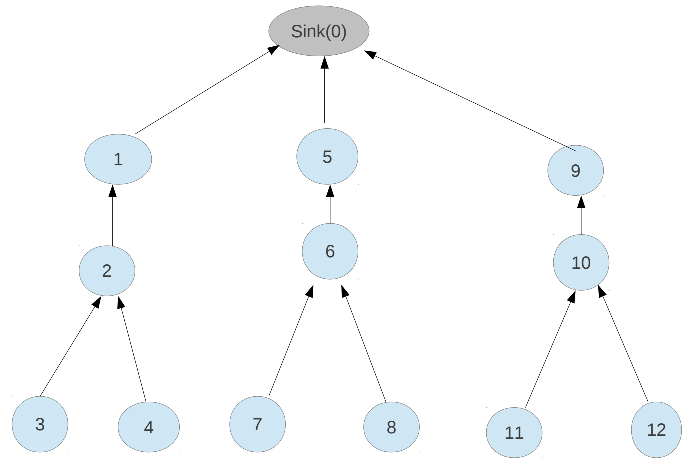

Fig. 3. Topology of the WSN in our simulation.

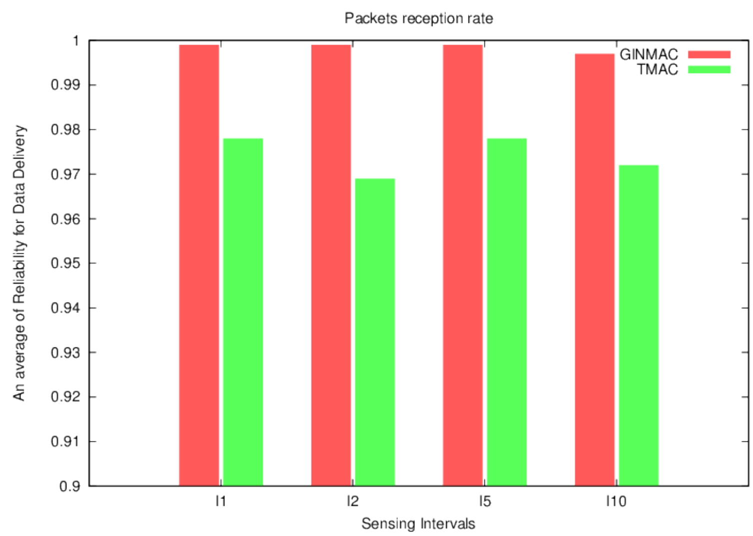

Fig. 4. Performances in term of Reliability using TMAC and GinMAC for Static scenario using different sensing intervals, see Section VI-A.

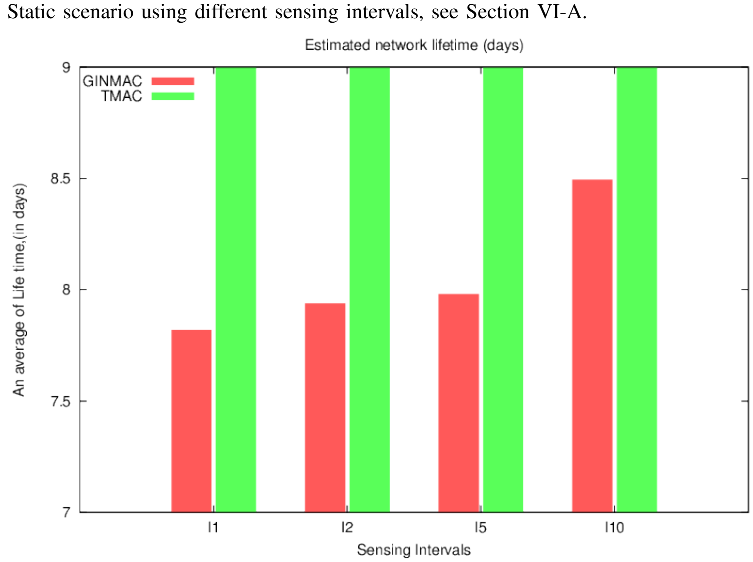

Fig. 5. Performances in term of life time of the nodes in networks using GinMAC and TMAC for Static scenario using different sensing intervals, see Section VI-A.

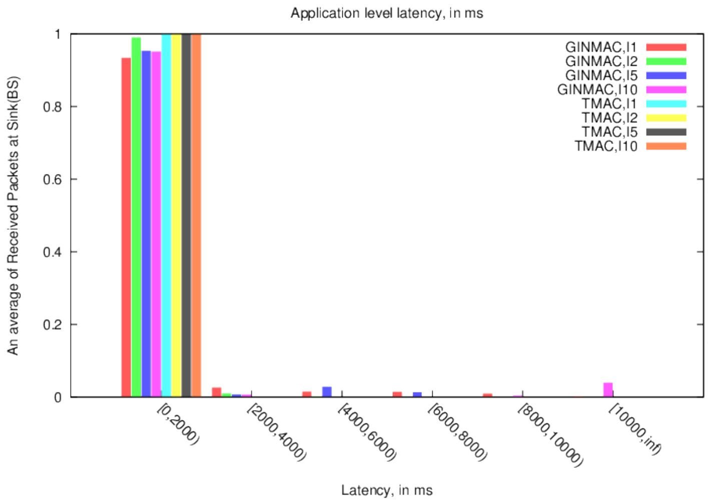

Fig. 6. Latency for delivered packets using TMAC and GinMAC for Static scenario using different sensing intervals, see Section VI-A.

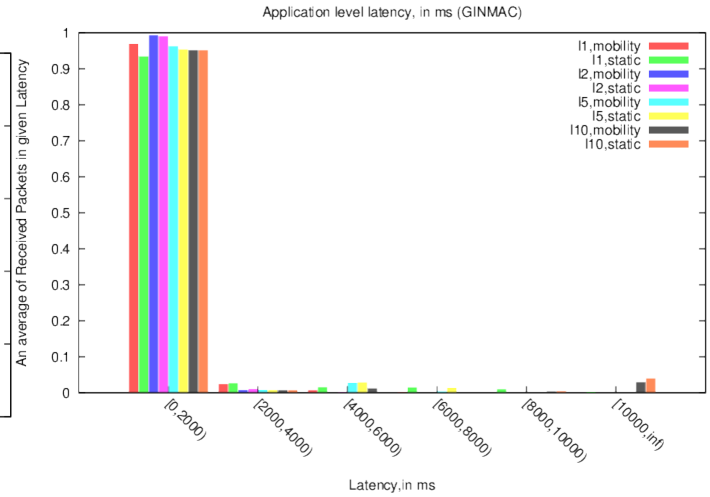

Fig. 9. Latency for delivered packets using both mobility and static scenarios for GinMAC using different sensing intervals, see Section VI-A.

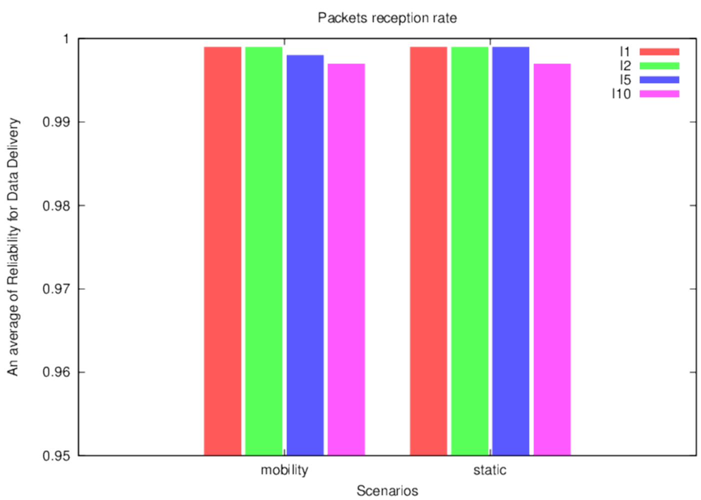

Fig. 7. Performances in term of Reliability using both mobility and static scenarios for GinMAC using different sensing intervals, see Section VI-A.

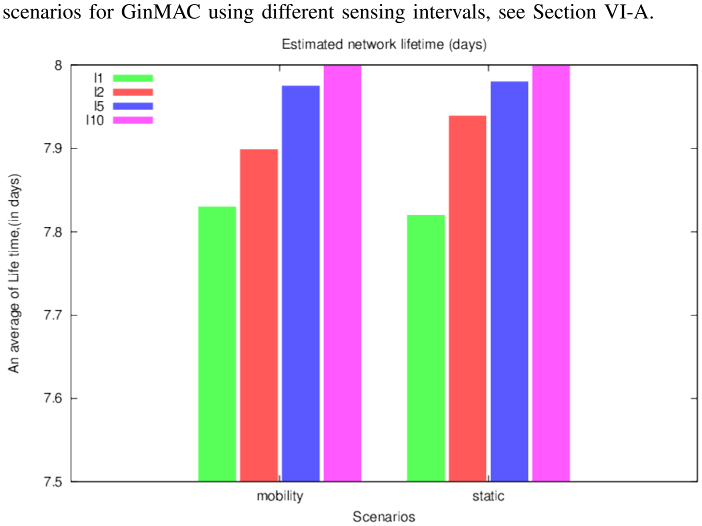

Fig. 8. Life time of the nodes in the network using both mobility and static scenarios for GinMAC using different sensing intervals, see Section VI-A.

from source nodes to a sink at given sensing intervals. This performance is due to the fact that GinMAC implements static TDMA schedules to allocate the required slots for nodes in the network and based on this, collision is reduced and reliability for delivered data is optimized. It can be said that GinMAC can be used for the proposed applications when the reliability is the biggest issue. However, TMAC cannot offer a reliability of more than 0.97 in both high and low sensing intervals using the same parameters.

GinMAC cannot offer reliability of more than 0.99 for sensing intervals more than 1 packets per second and if it is needed to increase this reliability for such sensing intervals, the number of slots for nodes in the static topology may be increased. But, GinMAC performs better than TMAC in both high and low sensing intervals as shown in the Figure 4.

2) *Energy Saving and Lifetime:* Figure 5 shows the average life time of the nodes in the network using GinMAC and TMAC using different sensing intervals. It can be seen that GinMAC cannot perform better than TMAC in terms of energy saving and life time of the entire network in all given sensing intervals, however, its performance is enough to be used in the proposed application. This is expected to be so, because of the adaptive related techniques for TMAC, which let nodes be active only when they have data to sent or received. GinMAC lets nodes be active even when they do not have data and hence consumes more energy. A WSN using GinMAC can survive more than 7 days at low sensing intervals and around 8 days at high sensing intervals as shown in Figure 5. This implies that GinMAC can be used for the proposed application when energy needs to be considered using a low number of nodes and high sensing intervals.

3) *Delay for Data Delivery:* Delay for delivered data using the proposed protocols in the proposed application is measured using *MaxLatency* and *MaxColumns* parameters. The *MaxLatency* parameter defines the bounded latency that all packets need to be delivered, which represents the threshold

for latency in the proposed applications. The *MaxColumns* parameter defines the number of columns to be used for measuring the latency for given MAC protocols. Initial values for these parameters are given in Table I, different values can be selected based on the requirement of the proposed application. Any delivered packets after the last column are considered to be lost and may be discarded. GinMAC does not perform better than TMAC in term of latency as shown in the Figure 6, however, this performance is good enough to be used for the proposed applications.

According to the results from Figure 6, most of the packets (which is about more than 0.98 of received packets) are received within the first 5 seconds at high sensing intervals, and the rest of packets are received within 10 seconds. Based on this and latency related parameters given in Table I, GinMAC delivers all packets within the required latency threshold value (*MaxLatency*). The reason behind this performance is that GinMAC implements static routes for delivering data based on static TDMA schedules between nodes and a sink and then delay for delivered data is reduced.

A. Results from the Proposed Mobility Scenario

The Mobility module for GinMAC considers the RSSI, remaining energy and short distance to select a better attachment. Based on this and as shown in Figures 7 and 8 show that GinMAC offers nearly the same reliability and lifetime for both static and mobility scenarios. However, mobile nodes consume a bit more energy than the static nodes as shown in the same figures, this is due to an extra overhead from the control messages from mobile nodes used by the proposed mobility module. Figure 9 shows that latency is the same as in the static topology and the required delay performance is unaffected using the mobility module. This implies that the proposed mobility module provides the good connectivity between nodes compared to the static scenario

B. Final Results

To conclude above results, reliability and energy saving are the most important performance criteria, which need to be guaranteed in the proposed healthcare application given in this paper, GinMAC achieves a very good performance in term of both reliability and energy saving using both mobile and static applications as shown above. This concludes that GinMAC can be used for the proposed application when the number of nodes is low.

VIII. Conclusion

An implementation of GinMAC including a proposed mobility module for a healthcare application where data needs to be collected from the body of patients and sent to a medical centre has been described in this paper. It has been shown that GinMAC can be used for the target application where the number of nodes is low. A mobility module has been designed and simulated for GinMAC for the proposed application. The results from the mobility module have also shown that this GinMAC implementation will give the same performance in both mobile and static scenarios. GinMAC assumes that all non mobile nodes have static routes toward their parents in advance and these routes cannot be changed. Based on this, GinMAC cannot provide the required routing for the proposed application when number of nodes is high or some nodes have died. Therefore, efficient routing protocols will also need to be designed to cooperate with GinMAC in order to provide the required routing and extend the life time of the network for the proposed application.

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