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# Modeling and Simulation of a Wireless Body Area Network for Monitoring Sick Patient Remotely

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*Abstract*-- **In recent years, substantial progress has been made in the medical field to integrate communication and information technology especially the Wireless Body Area Networks (WBANs) in healthcare systems for remote monitoring. WBANs have shown great potential in improving healthcare quality, and thus have found a wide range of applications from ubiquitous health monitoring and computer assisted rehabilitation to emergency medical response systems. WBAN operates in close vicinity to, on, or inside a human body andsupports a variety of medical applications. These types of applications can be further enhanced by integrating cloud computing technology for storing sensors' data. The information stored becomes available in the "cloud" from where it can be processed by expert systems and/or distributed to medical staff.**

**In this work we are interested in modeling and simulation of a wireless sensor network based solution allowing distributed sensor nodes to communicate with each other in an optimal way adapted to the specific constraints. More precisely, we want to build a IEEE 802.15.6 based wireless short range sensor exchanging data between them according to a communication protocol at MAC (medium access control) level that optimizes energy consumption, transmission time and loss of information.**

**Keywords: E-health, wireless Body Area Networks, IEEE 802.15.6, medium access control (MAC) protocols**.

## I. INTRODUCTION

There are tens of thousands of remote areas in developing countries, inter alia, Morocco, where the availability and exchange of data related to health may contribute to the prevention of the disease and save the life of thousands of people.

Appropriate monitoring of environment variables is also necessary to implement preventive measures at the local level or through appropriate government policies. The areas of health and food safety are raised on the agenda of objectives Millennium development Goals (MDGs) of the UN (United Nations) [1].

There are a variety of possible technical tools contributing to the solution of a social problem that is in a particular context. The questions of the complexity of the equipment, finance, local expertise, infrastructure deployment, were obstacles to make the most of these durable solutions.

The goal of our research is to find innovative and sustainable solutions to help improve the quality of health services in developing countries where the lack of qualified and competent staff (nurses, doctors, ...) and medical equipment are real problems facing developing countries, especially in the villages far from major health centers.

A wireless sensor network (WSN) is a communication network composed of wireless sensor devices. These devices essentially are low cost, low power, multi-functional, small sized and communicate over short distances. Typically these devices serve as nodes in a wireless network and are deployed randomly in a given area. Nodes establish connectivity with each other dynamically after deployment and do not follow a pre-determined topology and a specified protocol of communication. Therefore WSN are self-organizing in nature and are suitable for many fields and areas. One application of WSN is the monitoring of the health of patients remotely. Wireless sensor nodes are placed on patients and acquire sensitive data for remote monitoring by health care providers.

A significant amount of recent research has been done in the field of wireless body area networks with many researchers who propose different types of solutions for patient supervision. [2, 3, 4, 5, 6] are examples of such systems.

Within this context, the objective of this work is to model and simulate a heterogeneous wireless sensor network allowing the measurement and the transmission of short-range data collected by the environmental sensors. The planned network will be deployed in remote hospital centers and transmit health data and alert messages caused by a malfunction of environmental parameters to central hospital center via a continuous monitoring. So a limited scale, up to 20 nodes, seems to be sufficient for this monitoring application. These nodes exchange data between them according to a communication protocol that optimizes energy consumption, transmission delay and loss of information. Another principle to consider is that when any node fails, the network should repair automatically and must run normally with a minimal loss of information.

In fact, from the network point of view, key emphasis of this work is on WBAN which tries to provide low power, low cost and short-range solutions. Among them, IEEE 802.15.6 is considered as a promising way in terms of energy saving and guaranteed medium access. Therefore, we consider IEEE 802.15.6 as a starting point for our work. We optimized the parameters of the IEEE 802.15.6 physical layer and medium access control layer to better suite our specific constraints. The MAC layer has a fundamentaland significant impact in a protocol stack. The upper layers including network layer, transport layer, application layer, etc. will be considered after a robust MAC layer.

The paper is organized as follows: related works are discussed in section II, section III details our proposed system architecture. Section IV highlights the solution modeling of the WBAN and network setup for the simulation. Section V presents results of simulations, conclusion and future works are given in section VI.

## II. RELATED WORKS

There are already several prototypes of WSNs for remote health monitoring. For example in the CareNet project [7] an integrated wireless sensor environment for remote healthcare that uses a two-tier wireless network and an extensible software platform. CareNet provides both highly reliable and privacy-aware patient data collection, transmission and access.

Ayushman project is a sensor network based health monitoring infrastructure [8]. Ayushman provides a medical monitoring system that is dependable, energy-efficient, secure, and collects real-time health data in diverse scenarios, from home based monitoring to disaster relief.

The Medical Emergency Detection in Sensor Networks (MEDiSN) project [9] utilizes a wireless sensor network composed of a network gateway, physiological monitors (PMs), and relay points (RPs), to monitor the health and transmit physiological data of patients.The PMs are sensor devices which collect, encrypt and sign patients' physiological data (e.g., blood oxygen level, pulse, ECG, *etc.*) before transmitting them to a network of relay points that eventually forwards the data to the network gateway.

The European Community's MobiHealth System demonstrated the Body Area Network (BAN) consisting of software programs, hardware devices (including sensors) and Bluetooth communication between devices such as the MobiHealth GPRS Pregnancy Body Area Network [10]. The challenges of wireless networking of human embedded smart sensor arrays for a proposed retina prosthesis are described in [11].

However, studies on the use of IEEE 802.15.6 for remote health monitoring still few, and existing solutions need to be reviewed for more optimizations.

For example, the work done by Timmons and Scanlon which propose a BAN MAC, while at the same time arguing the non-suitability of the 802.15.4 MAC for BAN [12].

A new on-going project called BANET[13], which has as major objectives to provide a framework for Body Area Networks, define a reliable communication protocol, optimize BAN technologies and enhance energy efficiency of network components. The Project is led by CEA-Leti. It aims at defining precise frameworks to design optimized and miniaturized wireless communication systems. These body area networks target the medical field.

Our work does not propose a new MAC but rather lays the foundation for MAC design. Using appropriate simulation tools and channel models while, at the same time, not being tied to specific preconceived MAC techniques, we explore MAC techniques using the 802.15.6 MAC as our base.

## III. SOLUTION ARCHITECTURE

In this section, we describe our architecture solution which enables a healthcare institution, such as a Central Hospital Center (CHC), to manage data collected by WSN for sick patient supervision in Remote Healthcare Centers (RHC).

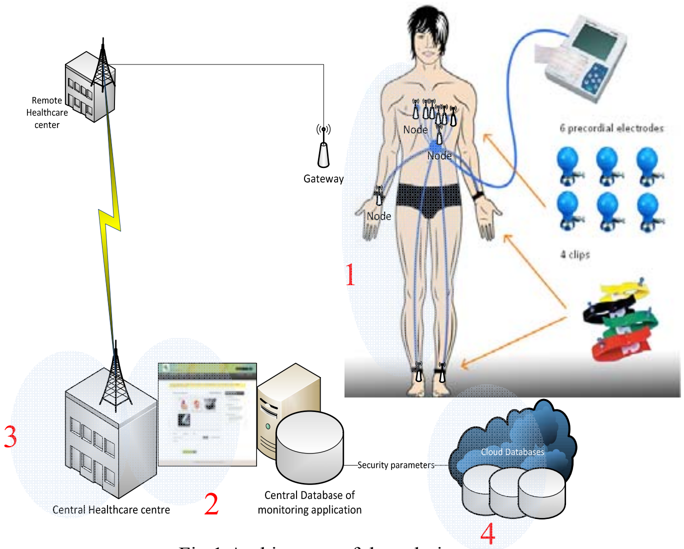


Fig.1 Architecture of the solution

The proposed solution aims to store a very large amount of data generated by sensors in the cloud. As these data are very sensitive, a new security mechanism to guarantee data confidentiality, data integrity and fine grained access control should be defined.

In the architecture described in Fig.1, we consider two categories of users, healthcare professionals and patients, and is composed of the following components: (1) the WBAN system which collects health information from patients, (2) the monitoring applications which allow healthcare professionals to access to stored data, (3) the Healthcare Authority (HA) which specifies and enforces the security policies of the healthcare institution and (4) the cloud servers which ensure data storage. By storing data on the cloud, our architecture offers virtually infinite storage capacity and high scalability.

## IV. WBAN SOLUTION MODELING

The simulation tool we choose is the Castalia open source simulator [14]. All simulations described in this paper are released with Castalia 3.2, assisting with the reproducibility of the results. Fig.2 shows the simulated network topology used throughout our simulations. One coordinator node at the right of the human body, and ten sensor nodes sending packets of 128 bytes (including overhead) to the coordinator.

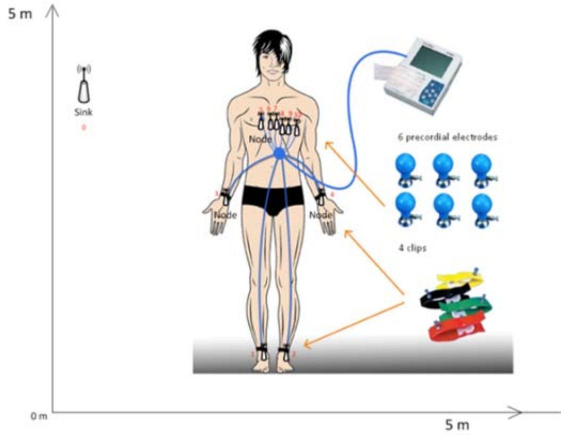


Fig.2 Simulated Network Topology

## A. *Wireless Channel*

### 1) *Path lossmap*

The aspect the most important of the wireless channel should we define is the average path loss between two nodes in space. For our case and generally in all WSN, the separation of nodes is a couple of meters. To give accurate estimate we use one of the most common radio models, which is the log-normal shadowing model. Manystudies [15,16] shown that this model provides more precise multi-path channel models than Nakagami and Rayleigh indoor environments [17]. The model is given by:

$$PL(d) = PL(d_0) + 10 \cdot \eta \cdot \log\left(\frac{d}{d_0}\right) + X_\sigma$$

Where d is the transmitter-receiver distance , PL(d) is the path loss ( in dB ) at distance d, $PL(d_0)$ is the known path loss at a reference distance $d_0$, η is the path exponent, and $X_\sigma$ is a Gaussian zero-mean random variable with standard deviation.

In BAN modeling, the model bellow does not produce good results. In this case we use an option that is given by Castalia simulator that is to explicitly set a path loss map for all nodes in a file. This mean that the file will contains the path loss experienced between each tow nodes. In our case we have defined 10 nodes and one coordinator (node 0). Table I shows the path loss values between each tow nodes.

Table I
Path loss between nodes

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | ********** | 69,6945009 | 70,623196 | 65,799229 | 68,919194 | 65,412121 | 65,635083 | 66,014146 | 66,276705 | 66,482093 | 66,782779 |
| 1 | 69,694501 | ********** | 51,77528 | 57,667584 | 60,273883 | 62,204934 | 62,281294 | 61,972439 | 61,893774 | 62,050515 | 62,050515 |
| 2 | 70,623196 | 51,7752801 | ********** | 60,273883 | 57,667584 | 62,357098 | 62,281294 | 61,814511 | 61,573039 | 61,491289 | 61,32584 |
| 3 | 65,799229 | 57,6675841 | 60,273883 | ********** | 59 | 54,825795 | 55,282353 | 55,4302 | 55,719749 | 56,275777 | 56,67416 |
| 4 | 68,919194 | 60,2738826 | 57,667584 | 59 | ********** | 55,861561 | 55,282353 | 54,184173 | 53,322272 | 52,57745 | 51,981684 |
| 5 | 65,412121 | 62,2049338 | 62,357098 | 54,825795 | 55,861561 | ********** | 27,77528 | 35 | 40,530774 | 43,681468 | 45,731793 |
| 6 | 65,635083 | 62,2812936 | 62,281294 | 55,282353 | 55,282353 | 27,77528 | ********** | 27,77528 | 35 | 39,89888 | 43,218144 |
| 7 | 66,014146 | 61,9724394 | 61,814511 | 55,4302 | 54,184173 | 35 | 27,77528 | ********** | 27,77528 | 35 | 39,89888 |
| 8 | 66,276705 | 61,8937743 | 61,573039 | 55,719749 | 53,322272 | 40,530774 | 35 | 27,77528 | ********** | 27,77528 | 35 |
| 9 | 66,482093 | 62,0505152 | 61,491289 | 56,275777 | 52,57745 | 43,681468 | 39,89888 | 27,77528 | 27,77528 | ********** | 27,77528 |
| 10 | 66,782779 | 62,0505152 | 61,32584 | 56,67416 | 51,981684 | 45,731793 | 43,218144 | 39,89888 | 35 | 27,77528 | ********** |

### 2) *Mobility Node*

In the case of node mobility, it is very complicated to take the average path losses between nodes in the space. One solution that will overlap this problem is to break up the space in discrete cells (Fig.3).Tow parameters should be defined here: the size of the field where the nodes are located and the cell size.

In our scenario, we define a 2 dimensional field 5m by 5m and a cell of 0.1 m. this result in 50*50 = 2500. This in turn results in $2500^{2}$ = 6 250 000 path losses.

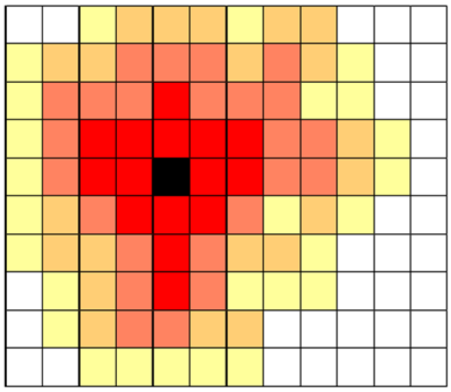

Fig.3 Path loss map in a 2D space segmented in cells (for a single transmitter cell)

For our proposed architecture, we consider that all nodes are mobile except node 0 (the coordinator).

### 3) *Temporal Variation*

Another very important aspect of the wireless channel is the temporal variation. This is especially pronounced in rapidly changing environments as those experienced in a BAN. In our simulation we based on the model given by the Castalia simulator. The model is based on a probability density function produced from experimental measurements [18].

## B. *Radio parameters*

To define the parameters of the radio to be used by wireless sensor nodes, we compared between commonly used wireless communications standards with BAN. IEEE 802.15 standards are focused on short range, low complexity, cheap and very low power consumption. It mainly focused on wireless personal area network (WPAN). And the standard group includes IEEE 802.15.1 Bluetooth, IEEE 802.15.4 ZigBee, and IEEE 802.15.6 Body area network. Our comparison will be between IEEE 802.15.4 ZigBee, and IEEE 802.15.6.

Table II
IEEE 802.15.6 and IEEE 802.15.4 comparison

| | **IEEE 802.15.6 BAN** | **IEEE 802.15.4 Zigbee** |
|---|---|---|
| **Supported applications** | Medical, Entertainment, Gaming, Sports, etc | Home, Industrial automation, Lighting, etc |
| **Range** | 2-5 m | 10-100m |
| **Data Rate** | Kbps-10Mbps | 20- 250 Kbps |
| **Power consumption** | 0.01 mW (stand_by mode) 40 mW (active) | 25-35mW |
| **Network size** | Modest; <256 devices per BAN | Huge; up to 65K devices |
| **Safety, Bio-friendly** | Meet regulation requirements for SAR and HIPPA | None |

Table II shows that the IEEE 802.15.6 is the most suitable for medical applications. BAN requires a shorter communication range, and important data rate, has extremely low power cost in its stand-by mode, and can provide enough power at its active mode, compare to ZigBee, this will benefit the device's life time, and its work performance. BAN meets certain safety and bio-friendly requirement, since the working environment is related to human body health.

The radio parameters we define that meet with the IEEE 802.15.6 radio proposal [19] are: frequency, data rate, modulation type, bits per symbol, bandwidth, noise bandwidth, noise floor, sensitivity and power consumed. We also define Tx levels in dBm and mv, delay transition between states, power transitions between states, and sleep levels. Table 3 gives the various radios parameters defined.

Table II
Radio parameters defined

| | |
|---|---|
| Data rate | 1,024Kbps |
| Modulation | Diff QPSK |
| Rxsensitivity | −87dBm |
| Noise bandwidth | 1MHz |
| Noise floor | −104dBm |
| Tx power | −10, −12, −15, −20, −25dBm |
| CCA time | 1ms |
| Tx→Rx and Rx→Txtransition times | 20µs |

*C. MAC layer*

For the MAC Layer, We have also implemented most aspects of the 802.15.6 MAC standarddescribed in the "MAC and Security Baseline Proposal", IEEE 802.15 documents [20].

Table IV
MAC default parameters defined

| | |
|---|---|
| Slot allocation length | 10 ms |
| Allocations slots in a beacon period | 32 slots |
| Requesting slots per node | 2 slots |
| Total allocation slots | 20 |
| Contention based access slots | 8 |
| Buffer MAC | 48 packets |
| Retransmission packets tries | 2 |

Table IV give the most important default parameters used in the simulation scenario.

The 128 byte data packet needs 1ms to be transmitted with the BAN radio used. Since though all data packets are required to be acknowledged, the total time for apacket (TX + ACK + radio state transition times) is 1.16ms. This means that there are 8 packets fitting in each allocation slot.

Calculating a theoretical max packet rate per node: If each node gets allocated 3 slots and gets to use 1of the 2 contention slots remaining then each node could transmit 32 packets/beacon period = 100 packets/sec. = 102Kbps per node. Thus all 10 nodes could ideally support 1020Kbps. As we will see in the simulation results, due to channel variations and protocol overhead practical rates are well below this limit.

All runs last 51secs (50secs for data and 1 secs used for network setup). Data are sent with 9 different rates. Each of the cases was executed 10 times with different random seeds.

## V. SIMULATION RESULTS

We observed performance metrics suchas received packets, packet outcome breakdown and latency. The results presented are averages on all nodes.Although differences between nodes (as a result of the differentlink qualities) are interesting, we do not have the space to present them in this paper.

*A. Received packets*

The received packets graph presented bellow (Fig.4) shows the average packets received per node (only node 0 receives packets but it receives them from multiple nodes) for different rates.

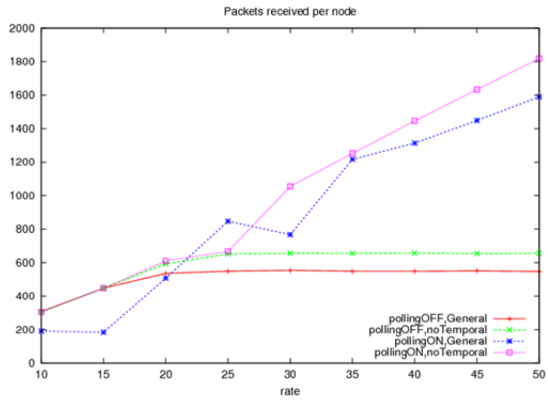


Fig.4 Packets received per node

We notice that the performance of the protocol is better when polling mechanism is turned on. It makes a more efficient use of the wireless medium and by reducing interference. We also notice better performance (packets received) when the channel has no temporal variation. This is to be expected as the temporal variation introduces some deep fades that break the connectivity between the sender nodes and the hub, whereas with the no temporal pathloss variation the links are kept in a relatively good state.

As to be expected when the protocol perform many packet tries, we notice a good efficiency in receiving packets (Fig.5).

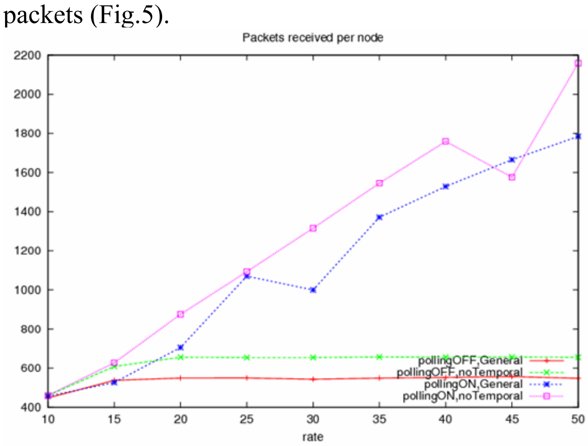


Fig.5: Packets received per node (packet tries=4)

### B. *Latency*

The latency of a successful packet is an important performance metric. If a packet is successful but arrives beyond a certain latency threshold the packet might be useless. The latency histogram presented bellow shows the distribution of latency (Fig.6) for three representative rates and three contention lengths for each rate.

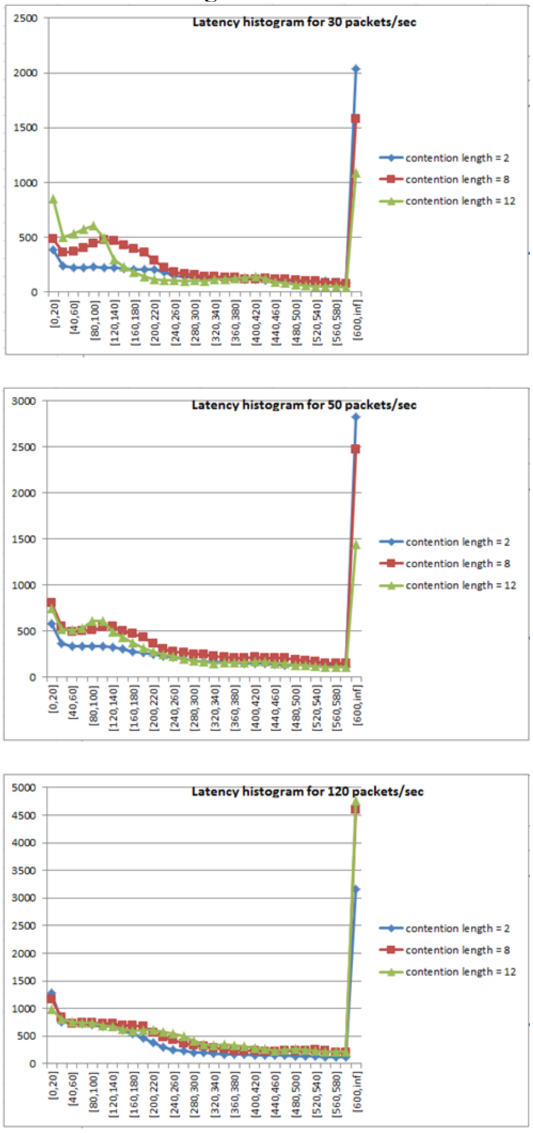


Fig.6 latency distribution for different rates

In the graphs above (Fig.6), we observe the effect of the contention period length for fixed rates. We notice that for low rates, large contention period lengths work the best, exhibiting the lowest delays. However, large contention period lengths in high rates present high delays. The graph for 50 packets/sec/node shows that the highest contention length performs poorly. There is a strong correlation on overflow packets and delays as one might expect. In general we note that long contention periods give the lowest delays for low rates but as the rates increase and the inefficiency of resource-usage is more apparent then we get longer delays. Short contention periods with large polling periods have the more stable performance in terms of latency.

### C. *Packets Breakdown*

We observe the packet breakdown at the MAC layer of the senders. The packets are divided into five categories: 1) success on the first time (i.e., an ack was received on the first transmission attempt), 2) success (i.e., an ack was received on the second or more transmission attempt), 3) NoAck (i.e. packet received no ack and was transmitted at least once on the radio), 4) Channel busy (i.e. packet failed because the CSMA mechanism never found the channel free, in all transmission attempts), 5) Overflow (i.e. the MAC buffer was full so the packet was rejected).

Fig.7 presents results for different cases in a comprehensive manner.

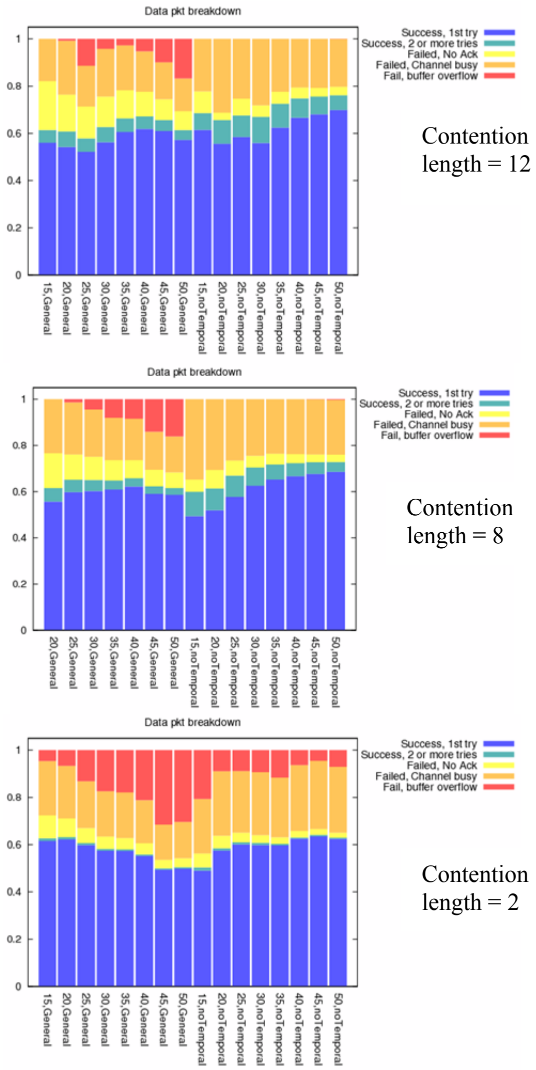


Fig.7 Data packets breakdown at the MAC layer

The horizontal axis of each graph varies the data rate for tow modes: General-pollinON and noTemporal-pollingON, starting with 15 packets/sec/node and going to 50 packets/sec/node. The vertical access shows the data packets breakdown.The results are shown as fractions of 1.

The first characteristic we notice is the overflow packets for the larger data rates. They show that even for traffics of 30 packets/sec/node we start to see clearly signs of saturation. Most interestingly though, the optimal contention length point is not the same for each rate. For the highest rate (50pkt/sec/node) the best option in terms of delivering more packets in clearly contention length of 12 slots. For 20 pkt/sec/node the best points are 8 slots of contention length. Also when looking at the graph we can get an immediate information on how better the result of the noTemporal case is.

## VI. CONCLUSION ANDFUTURE WORKS

Our Architecture delivers an integrated telemedicine service that automates the process from data collecting toinformation deliver. Several advantages in this paper have been presented, such as: providing always-on, real-time data collecting; eliminating manual collecting work and possibility of typing errors, and simplifying the deployment process.

Our Work will contribute to improve the quality of medical assistance delivery especially in needy remote healthcare centers, where the lack of medical staff and medical equipment is a big challenge.

It is difficult to gather medical staff with varying expertise in asingle place, and it is even more challenging to enable medical assistance to remote patients located in remote communities. In addition, expert medical staff has restricted time and cannot monitor patients or collect additional data from patients at bedside. Thus, the proposal presents an innovative solution that addresses problems of integration, such as medical staff from one institution being able tomonitor patients located at another. It also helps with releasing support staff workload that can use of saved time to focus on assistance. Finally, due to its pragmatic approachthe application results in a cost-effective solution to address the requirements for modernization of health-care system in developing countries.

In this paper, we discussed also the modeling and the simulation of the wireless body area network to be used in our architecture solution.

As future works, we intend to validate the proposal in a real world setup to assess the benefits of the solution inlarge scale scenarios. In addition, we intent to implement several services enhancements of security and management with interaction of thirty-party infrastructure service provider.

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