Configurable MAC Layer Access Modes for Challenging Environments in Body Area Networks

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ABSTRACT

Designing ultra low power MAC protocols for wireless body area sensor networks has been one of the interesting challenges due its unique channel characteristics and high reliability requirements. The recently published IEEE 802.15.6 standard offers a flexible superframe structure that can be adjusted by the hub to suit the communication requirements of the network and applications. However, the standard leaves the higher level questions open such as: should we use contention-based, scheduled, or improvised access, and under what conditions should we use them? Any MAC protocol that is looking to exploit these access modes should have a clear understanding of their parameters and operating characteristics. In this paper, we present a classifier-based configurable MAC modes for different healthcare applications and evaluate their performance. We considered a challenging scenario of a BAN with heterogenous nodes walking in a high interference environment and quantitatively compared the performance with contention-based and scheduled access modes. The simulation performance evaluation is carried out in OMNET++ with CASTALIA simulator framework. The performance improvements in configurable access mode offers key insights that could be translated to concrete design suggestions to build more efficient MAC protocols.

Categories and Subject Descriptors

C.2 [**Networks**]: Network Protocol Design

Keywords

IEEE 802.15.6, MAC access modes, Simulation performance

1. INTRODUCTION

The increasing use of wireless networks and the constant miniaturization of electrical devices have empowered the development of Wireless Body Area Networks (WBANs). IEEE 802.15.6 [1] is a standard for WBANs which is a short range, low power, and highly reliable wireless communication in the vicinity of, or inside, a human body. IEEE 802.15.6 has the potential to overcome the limitations of other standards, such as IEEE 802.15.1 (Bluetooth) and IEEE 802.15.4 (ZigBee) because of its purposeful design considerations and flexible superframe parameters to allow wider implementation and deployment of wireless body area networks. The IEEE 802.15.6 standard defines the physical layer (PHY) and Medium Access Control (MAC) layer for WBAN.

The unique characteristics of the wireless channel around human body, coupled with the need for extreme energy efficiency in healthcare applications require novel solutions in medium access control protocols. The wide range of sensors (e.g. ECG, EEG, pulse oximeter etc.,) have diverse data rate and QoS requirements. The main energy saving features a well designed MAC protocol must exhibit are: collision avoidance, minimal overhearing, control packet overhead and minimal receiver idle listening. An energy efficient MAC protocol is built on exploiting the underlying access mode and effective use of superframe structure. The IEEE 802.15.6 standard offers a flexible superframe structure that can be adjusted by the hub to suit the communication requirements of the hub. However, the standard leaves the higher level questions open such as: should we use contention-based, scheduled, or improvised access, and under what conditions should we use them? There is very limited evidence on how the MAC protocol exploit the access modes and its parameters effectively in BAN. In this paper, we present a classifier-based configurable access mode selection and evaluate the performance in high interference and mobile scenarios.

There are a few recent works analysing the characteristics of the access modes proposed in the standards. In [2] Rashwand *et al.* developed an analytical model for performance evaluation of the IEEE 802.15.6 standard under non-saturation regime. This paper argue that adopting appropriate user priorities and Exclusive and Random Access Phases (EAP1 and RAP1) lengths improves the performance of the network. In [3], the MAC performance of an IEEE 802.15.6-based WBAN operating over a Rician-faded channel was

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investigated. The paper analysed the impacts of channel fading and effects of the diversity level on MAC level performance of IEEE 802.15.6 CSMA-based WBANs. In [4] Ullah *et al.* analysed the delay and throughput limits for a single device using contention-based access. [2]-[4] considered contention-based access methods. Similar analysis for scheduled access was investigated by Tachtatzis *et al.* in [5] and [6], where the performance of scheduled access modes and the estimate lifetime of the devices was evaluated. In [7] the authors studied the different mixes of contention-based access and polling-based access. However, we are not aware of any literature analysing performance of different types of access modes against QoS requirements of multitude of heathcare applications. The need for selecting appropriate access modes to ensure the best use of 802.15.6 standard is emphasized in [5].

The main contributions of the paper are as follows: (1) we present a classifier-based configurable MAC access mode selection method and the superframe structure that configures adaptively for specific applications and operating environments, (2) the performance of the classifier-based configured access is quantitatively compared with contention-based and scheduled access. For this analysis, we considered a challenging scenario of a WBAN with 10 sensors of varying data rate requirements walking in high interference environment. The performance evaluation is conducted using OMNet++ discrete event simulator with CASTALIA framework. We investigated packet delivery and latency performance for different data rate traffic.

The remainder of this paper is organized as follows: Section II presents an overview of IEEE 802.15.6 standard. Section III presents the system model and simulation setup. Section IV describes the classifier-based configurable access framework and Section V presents performance of configured access modes through the packet delivery, packet drop reasons and latency. Finally, Section VI summarise the analysis and concludes the paper; we also provide some avenues for future research.

2. OVERVIEW OF IEEE 802.15.6

IEEE 802.15.6 is a standard for short-range, low-power, and highly reliable wireless communication in the vicinity of or inside a human body. It uses existing industrial scientific medical (ISM) bands as well as frequency bands approved by national medical and/or regulatory authorities. In this section, we present an overview of the IEEE 802.15.6 standard, with emphasis on MAC layer access modes; a more extensive description of the standard can be found in [1][9].

2.1 Physical Layer

IEEE 802.15.6 specification defines Narrowband (NB), Ultra-Wide Band (UWB) and Human Body Communications (HBC) physical layers and a common frame structure. The NB physical layer operates in seven different frequency bands with a variable number of channels, bit rates and modulation schemes.

2.2 MAC Layer Access Modes

IEEE 802.15.6 standard specifies a common MAC for all the supported physical layers and which can use one-hop star or two-hop restricted tree topologies. In these topologies, the hub is responsible for coordinating channel access by establishing one of the following three access modes:

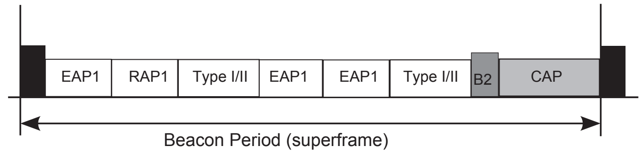


Figure 1: IEEE 802.15.6 Superframe

- Beacon mode with beacon period superframe boundaries
- Non-beacon mode with superframe boundaries
- Non-beacon mode without superframe boundaries

2.2.1 *Beacon mode with superframe*

In this mode, the hub transmits a beacon frame in each beacon period, except in inactive superframe, it provides time referenced allocation and divide the period into access phases supported in beacon mode as shown in Figure 1. The superframe structure of IEEE 802.15.6 is constructed of nine access phases, which are beacon, Exclusive Access Phase 1 (EAP1), Random Access Phase 1 (RAP1), Type I/II phase, Exclusive Access Phase 2 (EAP 2), Random Access Phase 2 (RAP 2), Type I/II phase, and a Contention Access Phase (CAP). Type I/II phase is alternatively referred to as managed access phase (MAP). Beacons are sent in the first slot of each superframe to initialize the superframe, identify the coordinator, facilitate network and power management, and clock synchronization.

2.2.2 *Non-beacon mode with superframe boundaries*

The transmission time relative to the start of current superframe is indicated by a timed frame (T-Poll), which is an equivalent of Poll frame that contain a transmit timestamp for superframe boundary synchronization. In this mode, the hub can improvise and unschedule also polling or posting can be employed as well. With this mode, a hub can have in any superframe only one type I or II access phase.

2.2.3 *Non-beacon mode without superframe boundaries*

For non-beacon mode without superframe boundaries, a hub can provide only the unscheduled type-II polling access.

It is quite common to find devices are implemented to operate in a single access mode, for instance, several of the existing commercial products often use only CSMA/CA for multiple access. A single preconfigured access mode cannot be expected to perform well in all varying conditions. There is a clear rationale to exploit the 802.15.6 flexible superframe by selecting appropriate access modes and making use of available sensor information.

3. SYSTEM MODEL

The performance evaluation of the IEEE 802.15.6 MAC access modes are carried out in OMNet++ discrete event simulator with CASTALIA framework [8]. The simulation set up considers on-body communications operating in 2.4 GHz ISM band, one of the candidate carrier frequencies considered in IEEE 802.15.6 standard. The network setup has a hub coordinator and 10 different sensors connected in a star fashion, as shown in Figure 2. To reflect a realistic scenario, we consider 10 sensors - five high data rate and five low data rate nodes. The placement of nodes over the body and mobility information are shown in Figure 2 - we placed one node in each wrist, each arm, each thigh, each ankle, one on chest and one near neck of considered subject.

The average path loss between every pair is calculated from measurements. Several channel models have been suggested for BANs [10][11]. These channel models are derived from a combination of analytical and measurement campaigns. For onbody to on-body communication with Line-Of-Sight (LOS) and Non-Line-Of-Sight (NLOS) scenarios:

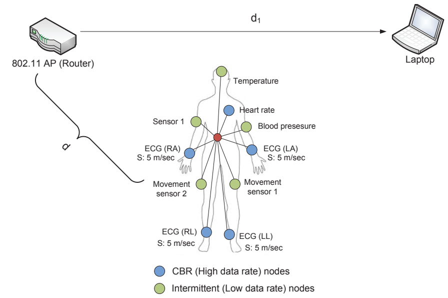
$$PL(d) = a.\log(d) + b + N \qquad (1)$$

where $PL(d)$ is the path loss in dB at a distance d mm, a and b denote parameters derived by a least square fitting to the measured average path loss over the frequency range, d is Tx-Rx distance and N is normally distributed variable with standard deviation σ_N. For indoor at 2.4 GHz, the values for the parameters are measured to be $a = 8.32$, $b = 37.2$, $\sigma_N = 2.5$.

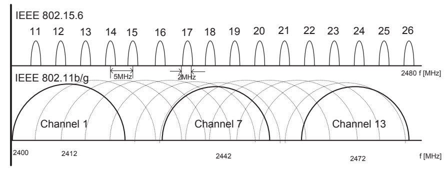
Regarding channel models, it has been concluded from measurements that the fast fading follows a Rice distribution with a high K-factor when the human subject is stationary, which means there is a strong dominance of main path from the energy contribution perspective [11]. However, under walking scenarios, the K-factor almost disappear. This means that the fading distribution is a Rayleigh fading model which makes transmissions even more challenging. The physical radio model follows the physical layer model described in IEEE 802.15.6 standards. Some of the important parameters are: data rate 1024 kbps, receiver sensitivity -87 dBm, transmission power -10 dBm. The changes in link quality from signal attenuation or interference can be assessed based on connectivity, packet reception rate (PRR) or RSSI. In the presence of interference, RSSI alone may not a correct indicator to determine the link state, so we use combination of parameters to assess the link quality.

3.1 Coexistence and Interference

In this study, it is envisaged that WBAN to be operating in 2.4 GHz ISM band. Due to non-availability of dedicated medical bands in Europe, coexistence of WBANs in 2.4 GHz ISM band is a critical issue. Several research papers have discussed this issue [12][13][14]. In this analysis, IEEE 802.11 is considered as the main source of interference, however this effect can be extended to other sources in the ISM band (such as IEEE 802.15.4) as well. The scenario is defined as follows: a person wearing WBAN is walking into a room with a IEEE 802.11b/g WiFi access point and a laptop, see Figure 2(a). For this study, we specify that WBAN operate in 16 different frequency channels in 2.4 GHz as shown in Figure 2(b), with center frequencies $(2405, 2410, \ldots, 2480$ MHz). The bandwidth B is 5 MHz when MSK modulation is used and 2 MHz when GMSK is used. As for IEEE 802.11, the 13 channels defined for Europe at 2.4GHz with center frequencies $(2412, 2417, \ldots, 2472$ MHz) [15].



(a) Interference Scenario



(b) 2.4 GHz ISM band and channels

Figure 2: Interference scenario in 2.4GHz ISM band

We assume the usage of channel 18 for WBAN in the presence of 'heavy' constant bit rate (CBR) traffic flow between the 802.11 AP and the laptop. In frequency domain, the percentage of interference (P_{int}) fraction ranges from 0.028% and 24.82%, corresponding to an interfering power fraction -15dBm to 14dBm, respectively, considering a transmit power of 802.11 devices set to +20dBm [12]. In this paper, we vary the interference levels from 5dBm to 20dBm.

3.2 Applications considered and requirements

The ISO/IEEE 11073 [17] provide medical device interoperability and specifies the required QoS facilitating exchange of medical devices data in all healthcare environments. The paper investigates the access modes satisfying the throughput and latency constraints of IEEE 11073. Figure 3 shows possible wearable sensors and their data rates that are applicable for smart healthcare applications. In this figure, sensors are categorized into sensing mechanism and 8 levels of data rate range. The sensors are categorized in, pressure variation, light reflection, electrical signals, acceleration, sound and visual types. The sensor type and data rate classifications could be used to decide the wireless access mode.

4. CLASSIFIER-BASED CONFIGURABLE ACCESS

Several varieties of healthcare monitoring sensors could be potentially attached to a hub. These sensors have a varying data rate and QoS requirements; this includes sampling rate, point-to-point delay and delay variation. For example, in real-time communication, the latency should be less than 250ms and jitter should be less than 50ms. Mobility and the challenging channel conditions around body makes it harder

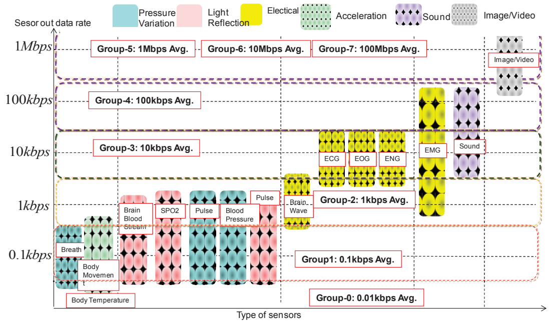


Figure 3: Selected BAN applications and data rate groups[16]

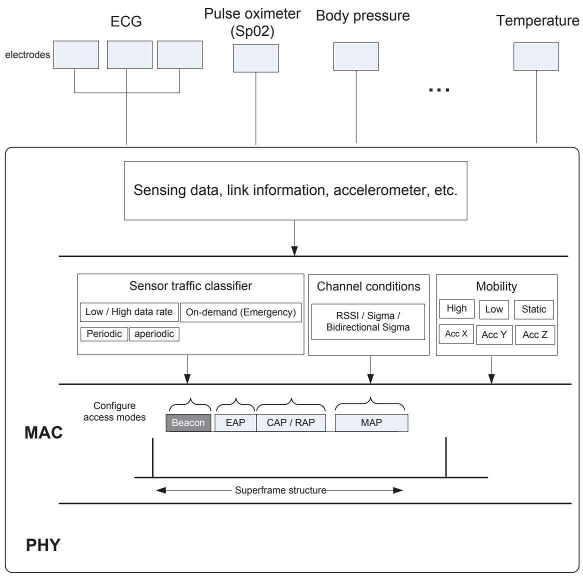


Figure 4: Classifier-based configurable access modes

to provide the reliable access with required QoS. A single pre-configured access mode cannot be expected to provide the required data rate and QoS in all varying conditions.

The rationale behind the classifier-based configurable access mode is that by efficiently exploiting some of the measured sensor information, the data rate and latency requirements of the diverse sensor applications can be achieved. The hub is responsible for coordinating the channel access by establishing the access modes. The 802.15.6 standard offers a flexible superframe structure with wide variety of parameters to configure. The superframe is configured to adapt to the changes in surrounding environment.

4.1 Classifier-based Configurable Framework

In Figure 4, a classifier-based configurable MAC access framework is presented. By effectively configuring the superframe structure an efficient MAC mode can be achieved. The choice of access mode and its superframe structure is configured according to (i) type of sensors (ii) operating channel conditions (iii) Mobility conditions. The classifier consists

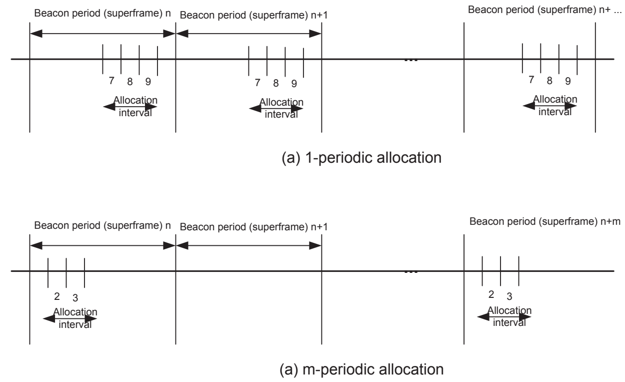


Figure 5: Periodic scheduled allocation modes

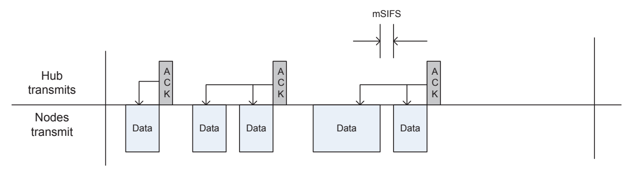


Figure 6: Interframe space during data transfer

of three components:

- Sensor traffic classifier: during initial sensor registration, the hub configures the sensor to one of the access modes types.
- Channel condition classifier: the link state information gathered from sensor (e.g. RSSI, σ). The relative change and rate of change in these values are statistically used for assessing and configuring.
- Mobility classifier: The framework gathers the coarse estimation of location and mobility from the accelerometer (and gyroscope).

The classifier configures when the BAN sensors are established during registration phase. If there are fewer sensors, the traffic classifier classify the sensors as high, medium or low. If several different sensors are attached and if more granularity is required, the framework classify using 8 groups (as shown in Figure 3). Several scenarios-based traffic modelling are already available, however, the variety of resolutions imposed by the devices make it challenging to characterize data traffic. For example, the sampling rate for temperature monitoring is much lower than that a real-time application. Also for ECG, the sampling frequencies and resolutions vary from 250 Hz to 720 Hz, and 12 bit to 11 bit, respectively. The data traffic is classified into three categories; constant bit rate (CBR), On-Off, and Impulsive [18].

Mobility of a BAN causes cochannel interference with other BANs or heterogenous networks. To accurately estimate the average path losses between the nodes, the lognormal shadowing model should capture the correlation between the two directions of a link. If you treat the two directions as independent links, the variance you get is much larger than the one experienced in reality. For this reason, in this model we use bidirectional sigma (σ_{bi}) that captures the correlation between the two directions of a link [8]. Received signal strength indicator (RSSI) is a measurement of the power present in a received radio signal. In the presence of interference, RSSI alone may not a correct indicator to determine the link state, so we use combination of parameters to assess the link quality.

With accelerometer widely prevalent in sensors, we exploit the absolute and relative position of the sensors. The (AccelX, AccelY, AccelZ) and relative difference is used to assess the mobility. With the availability of 9DoF (9 degrees of freedom)/ gyroscope sensors a comprehensive movement of the subject can be provided.

In this paper, we consider Beacon Mode with beacon period superframe boundaries. Due to the extremely high performance of scheduled allocation, the superframe is initially set with Type I/II access mode with 1-periodic or m-periodic scheduled allocation based on sensors attached (as shown in Figure 5). In the considered superframe, the parameters - beacon period length, proportion of the number of contention access slots, scheduled allocation and improvised access - are set for configuration. Upon receiving the Connection Assignment frame granting it scheduled uplink allocation intervals, the sensors may initiate a frame transaction with the hub at the start of each of the allocation intervals. Another important parameter for configuration is interframe space (pSIFS, pMIFS, pExtraIFS), as shown in Figure 6. In the uplink block transfers, the minimum interframe spacing (pMIFS) and short interframe spacing (pSIFS) represent the time between the data blocks which are critical in mobile conditions. A frame transaction in a scheduled uplink or downlink allocation interval, the node or the hub, respectively, may initiate another frame transaction pSIFS.

The key objective of the classifier-based access mode is to exploit the multitude of sensor information with minimum complexity. By using selected categories and statistical data from application layer, instead of using all the coarse information directly, this method is adaptive to the channel conditions and is computationally less intensive. The superframe structure is configured based on the changes in the classifier data. This framework can be implemented along with the MAC driver to exploit the application layer information. This has excellent scope for the cross-layer optimization towards efficient configurable access.

5. PERFORMANCE ANALYSIS OF ACCESS MODES

The objective of this performance analysis is to measure the performance of the variety of BAN sensors in high interference and mobile scenarios. Performance is evaluated in terms of received packets, packet delivery ratio, average delay (latency).

The performance evaluation of the MAC access modes are carried out in OMNet++ discrete event simulator with CASTALIA framework with the model described in Section II. Each beacon period (superframe) is composed of allocation slots of equal length and numbered from $0, 1, \ldots, s$, where $s \leq 31$. Each slot length is set to be 10ms. In this simulation study, the superframe is dynamically configured varying the periods/slots for scheduled and contention access modes accordingly. For fully scheduled access, the scheduled access takes 30 slots and non-zero CAP takes 2 slots. For fully contention-based access, all 32 slots for CAP. The MAC has a buffer to hold 48 packets. The packet size is set 2000 bytes. The physical layer radio model is similar to the IEEE 802.15.6 standard. The data rate is set at 1024 kbps, receiver sensitivity -87dBm, transmission power -15dBm. The protocol is set one retransmission if first packet is not successful.

In this study, each of the 5 high data rate sensors vary its data rate from 5 packets/sec to 50 packets/sec. In terms of data rate, each node transmits 10kbps - 100kbps to the hub. The 5 low data rate sensors transmit 1 packet in 10 seconds. Each simulation is run for 100 seconds and the values are averaged over 1000 simulations.

5.1 Performance Comparison

The performance of the classifier-based configured access is compared with contention access and fully scheduled access. Figure 7 shows the received packets performance of different access modes under high interference (20dBm). The contention access performs poorly and saturates for higher data rates. Due to its conservative approach, the node differs its transmission until the channel becomes idle and only fewer packets are transmitted. The detailed comparison performances are given in Figure 9 and 10. Fully scheduled allocation perform better, with received packets significantly higher than contention access. Fewer packets are dropped due to loss of acknowledgement packets, especially for mobile limb nodes. The configured access improves upon the scheduled access. By allowing a non-zero contention period, the ACK loosing nodes' performance is also improved. The received packet performance is highest when the majority of allocation is scheduled and the fewer nodes use contention slots.

The latency comparison performance is shown in Figure 8. The healthcare applications have stringent criteria on latency. The ratio of packets delivered with latency > 200ms are plotted. In contention access, the packets take longer time to reach the destination. In high interference scenarios, the nodes back off and differs its transmission until it becomes idle. In scheduled access, the packet delivery latency is lower. The latency is much lower in configured access, as the higher number received packets arrive before 100ms. This significant latency improvement and consistent delivery of packets are the main advantages of configured access.

The detailed performance comparison characteristics are explained in Figure 9 and 10. In Figure 9(a) (b) (c) shows the transmit and received packets performance for interference = 20dBm scenario. The packet delivery 'ratio' for contention access at high data rate is higher but the actual number of received packets is higher in the scheduled and configured access. Received packet performance for configured access is 2-5% better than the scheduled access. The latency characteristics in Figure 10 (a)(b)(c) illustrate that in configured access delivers the higher number of packets within 100ms. The latency performance is more controlled even at higher

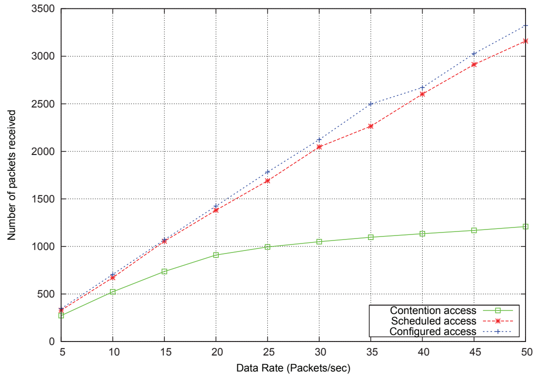


Figure 7: Received packets performance for different access modes

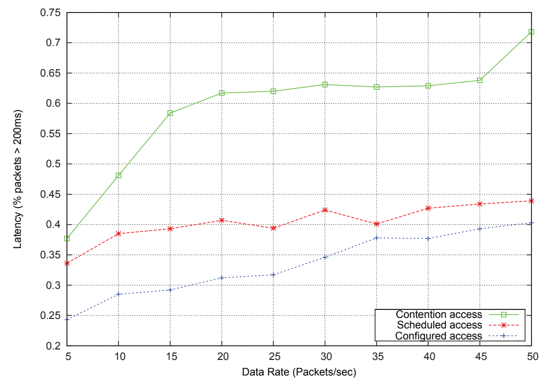


Figure 8: Latency performance comparison for different access modes

data rate scenarios, with over 20% more packets reaching before 100ms. For our simulation setup, through repeated testing we noticed that (scheduled=28 slots + contention=4 slots) and (scheduled=24 slots + contention=8 slots) setup produced better performances.

5.2 Performance under varying interference

Figure 11 and Figure 12 illustrate the received packets performance and latency performance for configured access with varying interference levels. The interference caused by 802.11 AP in the 2.4 GHz ISM band is usually bursty and this varying interference analysis is helpful in understand the effects. The linear projection of the received packets performance illustrate that the data rate could be increased further, however in contention access performance saturate after some data rate. Figure 12 shows the latency performance for different interference levels. The ratio of packets that are delivered > 200ms is minimal in the configured access.

In this analysis we also varied the beacon period. Figure 13 shows the received packets performance for different beacon periods. For this simulation setup, we noticed only a minor (0 to 2%) increase in received packets performance due to increased beacon period. Further analysis is required to measure the benefits of increasing beacon periods for other scenarios.

6. CONCLUDING REMARKS AND DISCUSSION

In this paper, we presented the performance analysis of classifier-based configurable IEEE 802.15.6 MAC access modes in high interference and mobile scenarios. The performance of the classifier-based configured access is compared with contention access and fully scheduled access. With the configured access that adapts to the changing environments, a higher number of packets are delivered and QoS is provisioned better. There is a significant improvement in latency compared to the fully scheduled allocation. With only selected classifiers and statistical data from application layer, the classifier-based framework is easier to implement as part of MAC driver.

Some concluding remarks based on our analysis is as follows:

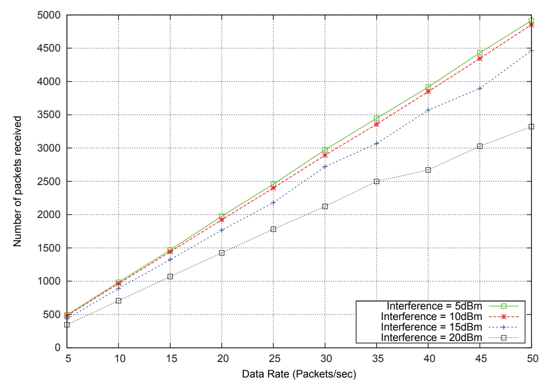


Figure 11: Configured access: Received packets performance for different interference levels

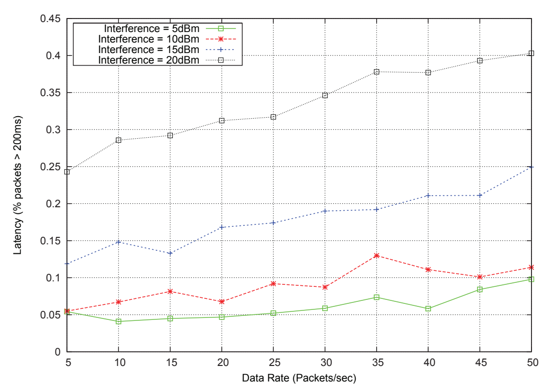
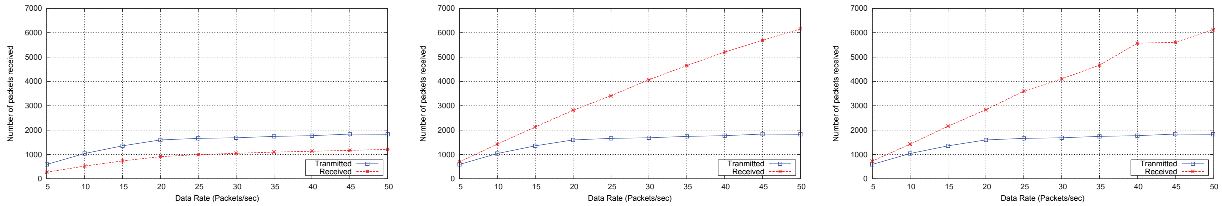
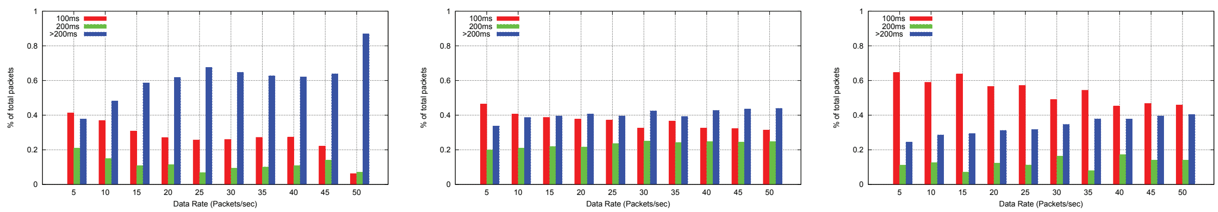


Figure 12: Configured access: Latency performance for different interference levels



(a) Fully contention access (b) Fully scheduled access (c) Configured access

Figure 9: Transmit - Received packets performance comparison (interference = 20dBm)



(a) Fully contention access (b) Fully scheduled access (c) Configured access

Figure 10: Latency performance comparison (interference = 20dBm)

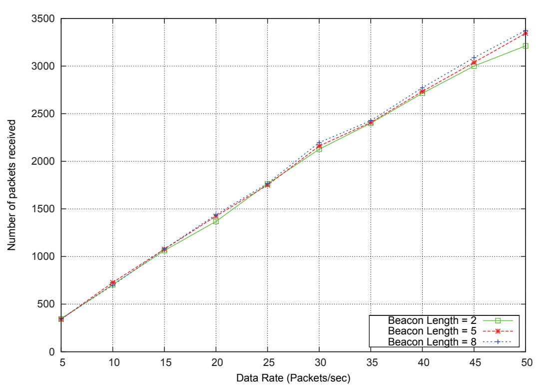


Figure 13: Received packets performance for different beacon fraction

1. The scheduled access performs better in terms of packet delivery ratio and latency. Scheduled allocation can either be 1-periodic or m-periodic depending on the sensor application. The number of slots allocated can be configured based on performance.

2. The standard allows devices to skip beacon periods, especially when the channel conditions are good. This provides flexibility and reduces energy consumption. The effective use of 1-periodic or m-periodic scheduled access, jointly with skipping beacon period would significantly improve the performance. The m-periodic scheduled access without beacon is the upper-bound of energy efficient performance.

3. The spectral utilisation of contention access is poor. However, the contention access performs better when the channel conditions are worse. The node differs its transmission until it becomes idle. The non-zero CAP slots mandated by the standard significantly helps during mobility and interference scenarios.

4. Efficient use of *guard time*: Each time slot is separated with *guard time* which is necessary to avoid clock drifts but this costs significant delay in real-time high data rate and results in extra energy waste. However, during mobile scenarios the *guard time* improves received packet performance.

We identified several research avenues on how the analysis can be extended. The selection of appropriate access modes and the optimal number of slots for each modes could be analytically modeled. This generic analytical model would be step closer towards optimally efficient low power MAC protocol. Also, the traffic-shaping models for dynamic channel conditions is another interesting research topic.

Acknowledgment

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7. REFERENCES

[1] IEEE 802.15.6: IEEE Standard for Local and metropolitan area networks - Part 15.6: Wireless Body Area Networks, 2012.

[2] S. Rashwand, J. Misic, "Performance Evaluation of IEEE 802.15.6 under Non-Saturation Condition," IEEE Global Telecommunications Conference (GLOBECOM), 2011.

[3] S. Rashwand, J. Misic, V. Misic, "MAC performance modeling of IEEE 802.15.6-based WBANs over Rician-faded channels," IEEE International Conference onCommunications (ICC), 2012.

[4] S. Ullah, Kyung Sup Kwak, "Throughput and delay limits of IEEE 802.15.6," IEEE Wireless Communications and Networking Conference (WCNC), 2011.

[5] C. Tachtatzis, F. Franco, D. C. Tracey, N. F. Timmons, J. Morrison, "An Energy Analysis of IEEE 802.15.6 Scheduled Access Modes for Medical Applications," ADHOCNETS, 2011.

[6] C. Tachtatzis, F. Franco, D. C. Tracey, N. F. Timmons, J. Morrison, "An energy analysis of the IEEE 802.15.6 scheduled access modes," IEEE Globecom Workshop on Mobile Computing and Emerging Communication Networks (MCECN), 2010.

[7] A. Boulis, D. Smith, D. Miniutti, L. Libman and Y. Tselishchev, "Challenges in Body Area Networks for Healthcare: The MAC," IEEE Communication Magazine, vol. 50, no. 5, 2012.

[8] CASTALIA simulator, http://castalia.npc.nicta.com.au/index.php

[9] N. Bradai, S. Belhaj, L. Chaari, L. Kamoun, "Study of medium access mechanisms under IEEE 802.15.6 standard," IEEE WMNC 2011.

[10] K. Yazdandoost, *et al.*,"Channel model for body area network (BAN)," July 2010, IEEE 802.15.6 technical contribution, document ID:15-08-0780-10-0006-tg6-channel-model.

[11] R. D'Errico and L. Ouvry, "Time-variant BAN channel characterization," in Proc. IEEE 20th Inter. Symp. on Personal, Indoor and Mobile Radio Communications (PIMRC), Sept. 2009.

[12] F. Martelli, R. Verdone, "Coexistence Issues for Wireless Body Area Networks at 2.45GHz," European Wireless 2012, Apr 2012.

[13] J-H. Hauer, V. Handziski, A. Wolisz, "Experimental Study of the Impact of WLAN Interference on IEEE 802.15.4 Body Area Networks," European Conference on Wireless Sensor Networks (EWSN), Feb 2009.

[14] J. Huang, G. Xing, G. Zhou, R. Zhou, "Beyond Coexistence: Exploiting WiFi White Space for ZigBee Performance Assurance," IEEE ICNP, 2010.

[15] IEEE 802.11 Std, IEEE Local and Metropolitan area networks - Specific requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications. 2011.

[16] T. Suzuki, H. Tanaka,S. Minami,H. Yamada, T. Miyata, "Wearable Wireless Vital Monitoring Technology for Smart Health Care," IEEE ISMICT 2013.

[17] ISO/IEEE 11073-10103 Health informatics - Point-of-care medical device communication - Part 00101: Guide Guidelines for the use of RF wireless technology

[18] A. Ahmed, A. Riedl, W.J. Naramore, N.Y. Chou, M.S. Alley, "Scenarios-based Traffic Modeling for Data Emanating from Medical Instruments in Clinical Environment," World Congress on Computer Science and Info. Eng., vol.1 pp 529-533, 2009.