

Optimizing Packet Generation Rate for Multiple Hops WBAN with CSMA/CA Based on IEEE802.15.6

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Received 8 March 2014; revised 8 April 2014; accepted 18 April 2014

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Abstract

Wireless Body Area Network (WBAN) is considered to apply to both medical healthcare and entertainment applications. A requirement for each application is different, *i.e.* high reliability for medical healthcare whereas high throughput for entertainment application. However, for both applications, low energy consumption is requested. Multiple hops technics have been researching in many fields of wireless system, e.g., ad hoc, mobile, ITS etc. and its energy-efficiency is reported to be high. We propose the multiple hops technic for WBAN, however, WBAN is different to another systems, almost sensors forward the vital data packet of another sensors while sensing and generating the data packet of itself. Therefore, according to a packet generation rate of all sensors, probabilities of successful transmission and packet loss because of collision, timeout and overflow, are changed. It means that the vital data is lost and the transmit power is wasted due to packet loss. In order to obtain the highest throughput and save the power, the successful transmission probability is analyzed and the packet generation rate is optimized for multiple hops WBAN that using CSMA/CA based on IEEE802.15.6. The numerical calculation result indicates that the optimized packet generation rate depends on the system model. Moreover, the relation between the system model, the optimized packet generation rate and the throughput is discussed in the paper.

Keywords

Multiple Hops Body Area Network, Optimal Packet Generation Rate, Successful Probability, Collision Probability, CSMA/CA of IEEE802.15.6

1. Introduction

Nowadays, elderly population in many countries are increasing and then in order to survey health situation of

elderly peoples under the limited financial resources and current medical service, it is important to remotely monitor a body status and a surrounding environment. Moreover, doctors are hard to know what is really happening when each body function is monitored and separated by a considerable period of time. This is reason why the monitoring of movement and all body functions in daily life are essential. One of the monitoring systems is wireless body area network (WBAN). WBAN consists of wireless sensors attached on or inside human body for monitoring vital health related problems, *i.e.*, Electro Cardiogram (ECG), ElectroEncephalogram (EEG), Electronystagmogram (ENG) etc. These sensors continuously monitor data and send to a coordinator, the coordinator gathers data of all sensors and sends to Health care center through existing network. On the other hand, according to quick development of manufacturing industry, many wireless devices are developed, especially the devices that are using the vital data and/or be used around the body, *e.g.*, wireless earphone, music/movie player, game and so on. Consequently, the high throughput is requested. Moreover, the long lifetime of battery meaning the low power consumption is important subject of WBAN. According to importance of WBAN, the standard IEEE802.15.6 was establish [1]-[4].

The transmission of sensors can be divided into 2 schemes; Scheme 1: all sensors transmit their data packet directly to the coordinator, Scheme 2: sensors transmit their data packet to coordinator via another sensor. At Scheme 1, the transmit power of sensors should use high because the coordinator isn't always close to. Therefore, the lifetime of batteries becomes shorter and each sensor causes an interference to almost all sensors in WBAN. Moreover, the connection between sensors and the coordinator maybe fails due to the interruption of body functions, especially when the human is moving. The research on physical (PHY) layer, media access control (MAC) layer and network layer of Scheme 1 are described in [5] [6] and the communication of implant sensors WBAN also was researched [7]. On the contrary, at Scheme 2, since each sensor transmits its data packet to neighbor sensors, the transmit power and the influenced area are small. Therefore, the number of interfered sensors decreases and the lifetime batteries increases. In additional, even the direct connection between a sensor to the coordinator is failed, the sensor can transmit to the coordinator via another sensors that connects to the coordinator. According to the advantage of multiple hops technic, in this paper, we focus on the multiple-hop WBAN system.

The multiple-hop system is being researched in many literatures of many fields, *e.g.* ad hoc network, mobile network, ITS system and so on [8]-[11]. The MAC layer, PHY layer, network layer and crosslayer of multiple hops scheme also are researched [12]-[15]. However, in these systems, senders send a data packet to receiver(s) via relays and relays just forward the received data packet. On the contrary, in WBANs, sensors forward the received data packet while monitoring a situation of body and generating the vital data by themselves. According to the number of generated packets at each sensor meaning the packet generation rate, probabilities of successful transmission and packet loss because of collision, timeout and overflow, are changed. It means that the vital data is lost and the transmit power is wasted due to packet loss. In order to obtain the highest throughput and save the power, the successful transmission probability is analyzed and the packet generation rate is optimized for multiple hops WBAN. The optimized packet generation rate is analyzed when factors of system model are changed. Since the standard IEEE802.15.6 was established for WBAN, the transmission scheme in this paper is indicated as carrier sense multiple access with collision avoidance (CSMA/CA) based on IEEE802.15.6.

The rest of the paper is organized as follows. We introduce a brief of standard IEEE802.15.6 in Section 2. Section 3 shows the system model and performance analysis of multiple hops WBAN. The numerical evaluation is expressed in Section 4. Finally, Section 5 concludes the paper.

2. Brief of Standard IEEE802.15.6

In this section, the standard IEEE802.15.6 is briefly described. The detail of this standard is represented in [1].

2.1. Physical Layer

The IEEE 802.15.6 defines three PHY layers, *i.e.*, Narrowband (NB), Ultra wideband (UWB), and Human Body Communications (HBC) frequency. The selection of each PHY depends on the application requirements. Since we focus on analysis performance of multiple hops WBAN based on CSMA/CA access scheme, any PHY can be applied, however, NB is considered as an example.

The NB PHY is responsible for activation/deactivation of the radio transceiver, Clear Channel Assessment (CCA) within the current channel and data transmission/reception. The Physical Protocol Data Unit (PPDU)

frame of NB PHY contains a Physical Layer Convergence Procedure (PLCP) preamble, a PLCP header, and a PHY Service Data Unit (PSDU) as given in **Figure 1**. The PLCP preamble helps the receiver in the timing synchronization and carrier-offset recovery. It is the first component being transmitted at the given symbol rate. The PLCP header conveys information necessary for a successful decoding of a packet to the receiver. The PLCP header is transmitted after PLCP preamble using the given header data rate in the operating frequency band. The last component of PPDU is PSDU which consists of a MAC header, MAC frame body, Frame Check Sequence (FCS) and is transmitted after PLCP header using any of the available data rates in the operating frequency band. A WBAN device should be able to support transmission and reception in one of frequency bands summarized in **Table 1**. (Further detail for the modulation and the channel coding can be found in [1] [2]).

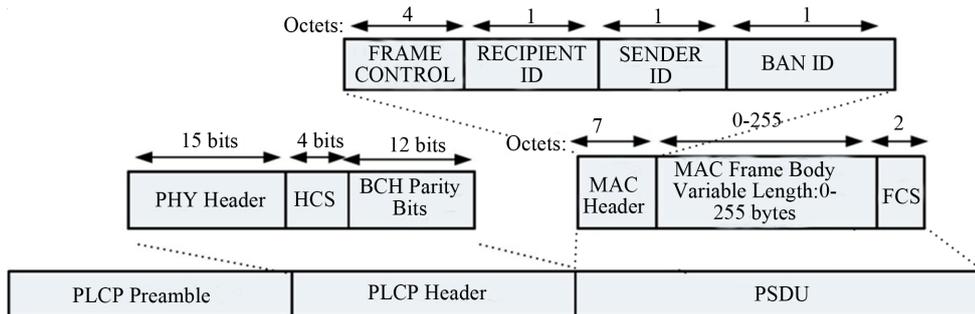


Figure 1. Structure of PPDU based on IEEE802.15.6.

Table 1. Main parameter for NB.

| Frequency band | Packet component | Symbol rate (Ksps) | Data rate (Kbps) |
|-------------------|------------------|--------------------|------------------|
| 420 - 450 MHz | PLCP header | 187.5 | 57.5 |
| | PSDU | 187.5 | 75.9 |
| | PSDU | 187.5 | 151.8 |
| | PSDU | 187.5 | 187.5 |
| 863 - 870 MHz | PLCP header | 250 | 76.6 |
| | PSDU | 250 | 101.2 |
| | PSDU | 250 | 202.4 |
| | PSDU | 250 | 404.8 |
| 902 - 928 MHz | PLCP header | 300 | 91.9 |
| | PSDU | 300 | 121.4 |
| | PSDU | 300 | 242.9 |
| | PSDU | 300 | 485.7 |
| 2360 - 2400 MHz | PLCP header | 600 | 91.9 |
| | PSDU | 600 | 121.4 |
| | PSDU | 600 | 242.9 |
| | PSDU | 600 | 485.7 |
| 2400 - 2483.5 MHz | PLCP header | 600 | 91.9 |
| | PSDU | 600 | 121.4 |
| | PSDU | 600 | 242.9 |
| | PSDU | 600 | 485.7 |
| | PSDU | 600 | 971.4 |

2.2. CSMA/CA Based on IEEE802.15.6

In IEEE802.15.6, there are three access mechanisms that be comprehensively discussed in the standard. 1) Random access mechanism, which uses either CSMA/CA or a slotted Aloha procedure for resource allocation, 2) Improvised and unscheduled access (connectionless contention-free access), which uses unscheduled polling/posting for resource allocation, and 3) Scheduled access and variants (connection-oriented contention-free access), which schedules the allocation of slots in one or multiple upcoming superframes, also called 1-periodic or m-periodic allocations. Because of high flexibility and extensibility of CSMA/CA, it is considered in our analysis. The CSMA/CA procedure defined in the IEEE 802.15.6 standard is shown in **Figure 2** and its basic procedure is explained as follows.

A sensor sets its backoff counter to a random integer number within $[1, CW]$ where $CW \in (CW_{min}, CW_{max})$ is the contention window of this sensor. The values of CW_{min} and CW_{max} change depending on the user priority (UP) as given in **Table 2**. The sensor decreases the backoff counter by one for each idle CSMA slot of duration. Particularly, the sensor treats a CSMA slot to be idle if it determines that the channel has been idle between the start of the CSMA slot and clear channel assessment of duration time ($pCCATime$). If the backoff counter reaches zero, the sensor transmits a data packet. If the channel is busy because of transmission of another sensor, the sensor locks its backoff counter until the channel is idle. The CW is doubled for even number of failures until it reaches CW_{max} . The failure means that the sensor fails to receive an acknowledgement from the coordinator. In random access period (RAP) 1, the sensor firstly waits for short interframe space ($SIFS$) = $pSIFS$ duration and then unlocks the backoff counter until it reaches zero where the transmission starts. But the sensor fails to receive an acknowledgement and the contention fails. As explained above, the CW is not doubled for odd number of failures and therefore the sensor sets its backoff counter to 5 and locks it. In contention access period (CAP), the sensor locks its backoff counter at 2 since the time between the end of the slot and the end of the CAP is not enough for completing the data transmission and the Nominal Guard Time represented by GT_n . The backoff counter is unlocked in the RAP2 period. Again the sensor fails to receive an acknowledgement and the contention fails. The CW gets doubled (for even number of failures) and the backoff counter is set to 8. When the data transmission is successful, the CW is set to CW_{min} . Further details of CSMA/CA procedure can be found in the standard [1] [2].

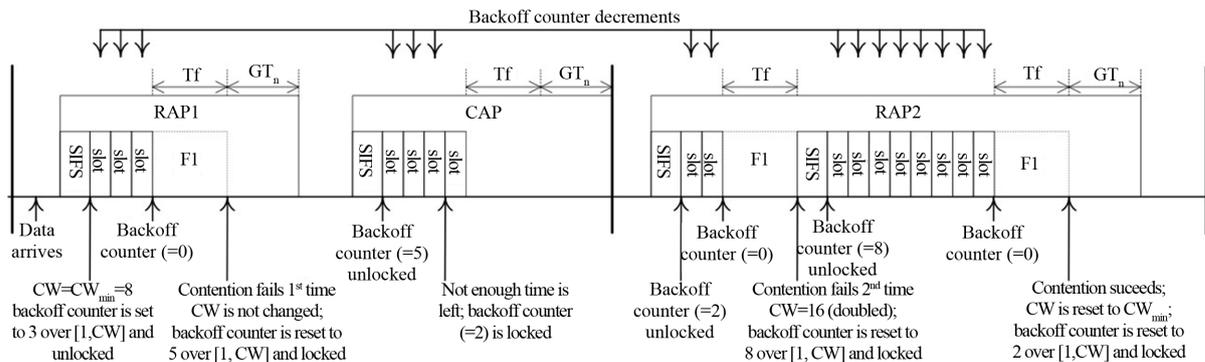


Figure 2. An example of IEEE802.15.6 CSMA/CA procedure.

Table 2. Contention window bound for CSMA/CA.

| User priority | CW_{min} | CW_{max} |
|---------------|------------|------------|
| 0 | 16 | 64 |
| 1 | 16 | 32 |
| 2 | 8 | 32 |
| 3 | 8 | 16 |
| 4 | 4 | 16 |
| 5 | 4 | 8 |
| 6 | 2 | 8 |
| 7 | 1 | 4 |

2.3. Calculation of Service Time

The service time (T) is defined as total time to transmit a data packet included the *backoff* time (T_{CW}), the time to transmit a data packet (T_{data}), interframe spacing (T_{pSIFS}), the time of acknowledgement packet (T_{ACK}) and delay time (α).

$$T = T_{CW} + T_{DATA} + T_{ACK} + 2T_{pSIFS} + 2\alpha. \quad (1)$$

Let's T_s denote a CSMA slot length, according to the standard, the average backoff time can be obtained as follows.

$$T_{CW} = \frac{CW_{\min} T_s}{2}. \quad (2)$$

As shown in **Figure 1**, since a data packet consists of a preamble, physical header, MAC header, MAC frame body and frame check sequence, the time to transmit a data packet becomes as

$$T_{DATA} = T_p + T_{PHY} + T_{MAC} + T_{BODY} + T_{FCS}, \quad (3)$$

here T_p , T_{PHY} , T_{MAC} , T_{BODY} , T_{FCS} represent the time to transmit a preamble, physical header, MAC header, MAC frame body and frame check sequence, respectively.

Since an immediate acknowledgement carries no payload, its transmission time is given by

$$T_{ACK} = T_p + T_{PHY} + T_{MAC} + T_{FCS}. \quad (4)$$

3. Multiple Hops Body Area Network System

3.1. System Model

Figure 3 shows an example of WBAN system. Many sensors are distributed around the body to monitor the health situation. Sensors transmit their vital data packet toward the coordinator. However, due to the interruption of body, some direct links between sensors and the coordinator is interrupted and the data packet of these sensors can't reach to the coordinator, especially, when the human is moving. Therefore, the multiple hops WBAN system is considered. According to multiple hops, a sensor that is out of transmission range of coordinator, can transmit its data packet to the coordinator via other sensors. We consider one link of multiple hops WBAN system consists of three sensors, A, B and C. The sensor A transmits its data packet to the sensor B, the sensor B transmits the received data packet as well as the data packet of itself to the sensor C and the sensor C forwards the received data packet and transmits its data packet to the coordinator (**Figure 4**). The WBAN system is constructed on or/and in the body, it means the space and the number of sensors are limited. Therefore, the multiple hops WBAN system has only few hops; it is different to other multiple hop systems, *i.e.* ad hoc, ITS and so on. This is the reason why the three hops of WBAN is considered.

The system model of multiple hops WBAN is described as follows. Since the packet loss due to collision is analyzed in this paper, the noise free is assumed. Therefore, packets are lost because of only collision of packets transmission in the same time. A link that consists of three sensors and one coordinator, is considered, and this link is assumed to be independent to another links and sensors. All sensors can transmit a packet to the neighbor sensor/coordinator only, however, all sensors in this link can sense the transmission of the others. The vital data packet is generated at each sensor by its packet generation rate. We assume that the system is started at time $t = -\infty$, hence it reaches its steady-state at the time $t = 0$. The buffer size of every sensors and the delay time of all packets are assumed to be limited, hence, if the throughput is smaller than the generated data meaning all the generated data aren't transmitted, the packets that aren't transmitted to the coordinator, will be lost. It is a reason of wasting transmit power and decreasing throughput of system. Consequently, in order to transmit all generated packets to the coordinator, the packet generation rate should be optimized.

3.2. Probabilities of Transmission Data

The transmission probability is defined as probability of sensor i in which the backoff counter is zero and denoted by Bf_i . A sensor can fail in transmission when more than one sensors send their data packet at the same time, namely collision of data frame. The backoff counter of a sensor counts down to zero when this sensor is in a transmission and the channel is idle (the channel is ready to transmit). If the channel is busy, the

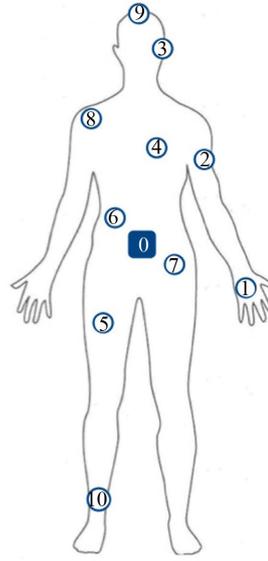


Figure 3. Body area network.

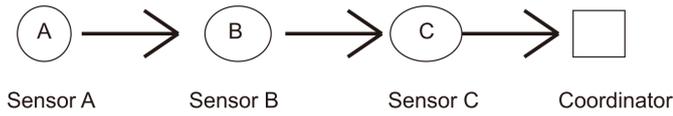


Figure 4. Multiple hops WBAN system.

sensor stops counting down its backoff counter. Therefore, the transmission probability is equal to the probability that the channel is ready to transmit $\left(\prod_{j \neq i} (1 - Bf_j)\right)$. In this paper, we assume that all sensors follow the same mechanism. Therefore the transmission probability of all sensors is the same as Bf and can be expressed as

$$Bf = (1 - Bf)^{n-1}, \quad (5)$$

where n is the number of sensors that is in transmission.

A sensor transmits a data packet successfully when only one sensor transmits the data packet. Let's P_{succ} denote the successful probability of transmission data of sensor i .

$$P_{succ_i} = Bf_i \prod_{j \neq i} (1 - Bf_j). \quad (6)$$

The collision probability (P_{coll}) is the probability that the data packet transmitted by sensor i collides with at least one of another data packets. It is the production of the transmission probability of sensor i (Bf_i) and the probability at least one sensor transmits a data packet $\left(1 - \prod_{j \neq i} (1 - Bf_j)\right)$.

$$P_{coll_i} = Bf_i \left(1 - \prod_{j \neq i} (1 - Bf_j)\right). \quad (7)$$

The collision probability of sensor i also can be calculated from another view point. It is the probability of unsuccessful transmission data of sensor i within the transmission probability (Bf_i).

$$P_{coll_i} = Bf_i - P_{succ_i} = Bf_i - Bf_i \prod_{j \neq i} (1 - Bf_j). \quad (8)$$

Compare the P_{coll_i} in (7) and (8), it is the same.

3.3. Analysis Performance of Multiple Hops WBAN

The packet generation rate of sensors A, B and C is denoted by λ_A , λ_B and λ_C ; furthermore, the number of

packets in queue at sensors A, B and C is q_A , q_B and q_C , respectively. Let's l represent the maximal number of transmission packets in one unit time, therefore $l = \frac{1}{T}$. We analyze the performance of multiple hops in one unit time started from $t=0$. For each duration of T , the number of packets that is successfully transmitted from sensor i is equal to the successful probability (P_{succ_i}). The sensor i is assumed to successfully transmit one packet after k times of T duration, hence after duration $[0,1]$, the remained packets is $q_i = \lambda_i (1 - P_{succ_i})^k$. All generated packets at sensor i are successfully transmitted if $q_i < 1$. The number of T durations in which the sensor i has a packet to send whether the backoff counter of sensor i is zero or not, is denoted as $tran_i$.

$$tran_i = \lambda_i \sum_{j=0}^{k-1} (1 - P_{succ_i})^j = \lambda_i \frac{1 - (1 - P_{succ_i})^k}{1 - (1 - P_{succ_i})} = \lambda_i \frac{1 - (1 - P_{succ_i})^k}{P_{succ_i}}. \quad (9)$$

In the proposed system, the sensor A transmits its data packet to the sensor B, the sensor B transmits the data packet to the sensor C and then the sensor C transmits the data packet to the coordinator. Therefore if the sensor A has the packet to transmit, the sensor B also has the packet to transmit, and if the sensor B has the packet to transmit, the sensor C also has the packet to transmit. All sensors are assumed to be equal in priority, therefore the successful probability, the collision probability of all sensors are the same. In case the sensor A is in transmission, the number of sensors that is in transmission (n) is three, the system in this case is indicated for Scheme 1. Furthermore, the successful probability in Scheme 1 is denoted by \dot{P}_{succ} . At Scheme 2, the sensor A isn't in transmission, the sensors B and C transmit with the successful probability \ddot{P}_{succ} and at Scheme 3, the sensors A and B aren't in transmission, the sensor C transmits with the successful probability $\ddot{\ddot{P}}_{succ} = 1$.

Let's \dot{k} , \ddot{k} and $\ddot{\ddot{k}}$ denote the average number of T durations to successfully transmit one packet of the Schemes 1, 2 and 3, respectively. The $tran_A$, $tran_B$ and $tran_C$ are described as follows.

$$\begin{aligned} tran_A &= \lambda_A \frac{1 - (1 - \dot{P}_{succ})^{\dot{k}}}{\dot{P}_{succ}}, \\ tran_B &= tran_A + \lambda_B \frac{1 - (1 - \ddot{P}_{succ})^{\ddot{k}}}{\ddot{P}_{succ}}, \\ tran_C &= tran_B + \lambda_C. \end{aligned} \quad (10)$$

The performance of system is analyzed in an unit time. If $tran_A \leq l$, all packets of the sensor A are transmitted to the sensor B. If $tran_A > l$, some packets are remained at the sensor A. Similar to the sensor A, if $tran_B \leq l$, all packets of the sensor B (included the packet received from the sensor A) are transmitted to the sensor C; if $tran_B > l$, some packets of sensor B are remained at the sensor B. If $tran_C \leq l$, all packets of sensor C (included the packet received from the sensor B) are transmitted to the coordinator. If $tran_C > l$, some packets are remained at the sensor C. Consequently, in case $tran_C \leq l$, all packets of sensors A, B and C are transmitted to the coordinator.

3.4. Optimizing Packet Generation Rate

As the analysis in previous section, packets of all sensors are transmitted to the coordinator if the packet generation rate is low. The optimal packet generation rate is defined as the maximum packet generation rate with that all packets of sensors A, B and C can be transmitted to the coordinator. The optimal packet generation rate is denoted as λ_{opt} . The optimal packet generation rate should be found in order to save the energy consumption and obtain the highest throughput.

As mentioned above, all packets of sensors can be transmitted to the coordinator if $tran_C \leq l$. Therefore, the optimal packet generation rate is the value that can satisfies $tran_C = l$.

$$l = tran_B + \lambda_{opt} = tran_A + \lambda_{opt} \frac{1 - (1 - \ddot{\ddot{P}}_{succ})^{\ddot{\ddot{k}}}}{\ddot{\ddot{P}}_{succ}} + \lambda_{opt} = \lambda_{opt} \frac{1 - (1 - \dot{P}_{succ})^{\dot{k}}}{\dot{P}_{succ}} + \lambda_{opt} \frac{1 - (1 - \ddot{P}_{succ})^{\ddot{k}}}{\ddot{P}_{succ}} + \lambda_{opt}. \quad (11)$$

Hence,

$$\lambda_{opt} = \frac{l}{\frac{1 - (1 - \dot{P}_{succ})^{\dot{k}}}{\dot{P}_{succ}} + \frac{1 - (1 - \ddot{P}_{succ})^{\ddot{k}}}{\ddot{P}_{succ}} + 1}. \quad (12)$$

In (12), the variables \dot{k} and \ddot{k} are indeterminate. In order to determinate the variables \dot{k} and \ddot{k} , the remained packets of sensors A and B after duration $[0,1]$ is considered.

$$\begin{aligned} q_A &= \lambda_{opt} (1 - \dot{P}_{succ})^{\dot{k}}, \\ q_B &= \lambda_{opt} (1 - \ddot{P}_{succ})^{\ddot{k}}. \end{aligned} \quad (13)$$

All packets of sensors A and B are transmitted to the sensor C if $q_A, q_B < 1$. Therefore, the \dot{k} and \ddot{k} are the minimum number that satisfies $q_A, q_B < 1$. It means that \dot{k} and \ddot{k} are the number with that $q_A, q_B \rightarrow 1$. From (12) and (13), the λ_{opt} is expressed as

$$\lambda_{opt} = \frac{\frac{1}{\dot{P}_{succ}} + \frac{1}{\ddot{P}_{succ}} + l}{\frac{1}{\dot{P}_{succ}} + \frac{1}{\ddot{P}_{succ}} + 1}. \quad (14)$$

4. Numerical Evaluation

4.1. Successful Probability

According to (5) and (6), the successful probability of Schemes 1, 2 and 3 (corresponding to the number of sensors in transmission is 3, 2 and 1) can be calculated and shown in **Figure 5**. The successful probability decreases rapidly when the number of sensors in transmission increases.

4.2. Theoretical Result

In order to evaluate the theoretical analysis, the parameter that is summarized in **Table 3**, is used as an example. Hence, $T = 0.0099$ second and the maximal number of transmission packets l is 100.9 times per second. According to (14) and successful probability in **Figure 5**, the optimal packet generation rate is 9.3 packets per second. The number of successfully transmitted packets of all sensors is shown in **Figure 6**. The number of

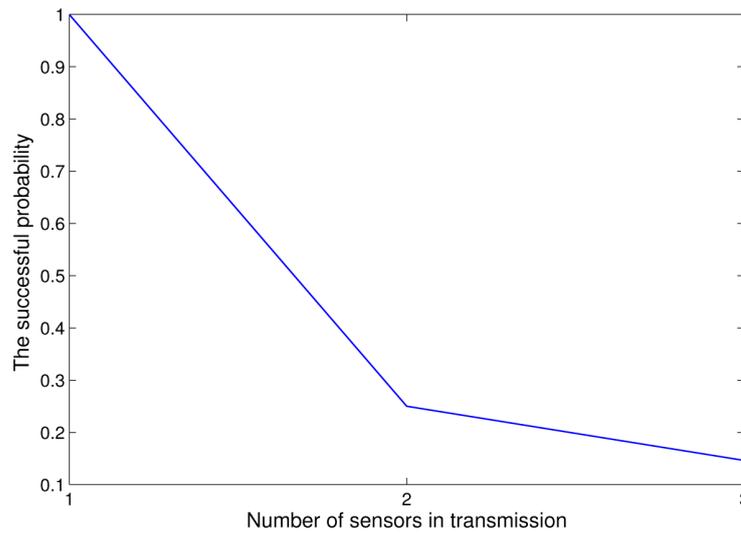


Figure 5. The successful probability of Schemes 1, 2 and 3.

Table 3. Numerical parameters.

| | |
|---|----------------|
| Frequency band [MHz] | 2400 - 2483.5 |
| Packet component | PSDU |
| Modulation | $\pi/2$ -DBPSK |
| Symbol rate R_s [Ksps] | 600 |
| Physical header rate R_{hdr} | 242.9 |
| Payload size [byte] | 250 |
| Minimum contention windows CW_{min} | 16 |
| Maximum contention windows CW_{max} | 64 |
| Clear channel assessment time | $63/R_s$ |
| MAC header [byte] | 56 |
| MAC footer [byte] | 16 |
| Minimum interframe spacing time [μ s] | 20 |
| Short interframe spacing time T_{sifs} [μ s] | 50 |
| Transmission time of preamble [s] | $88/R_s$ |
| Propagation delay α [μ s] | 1 |

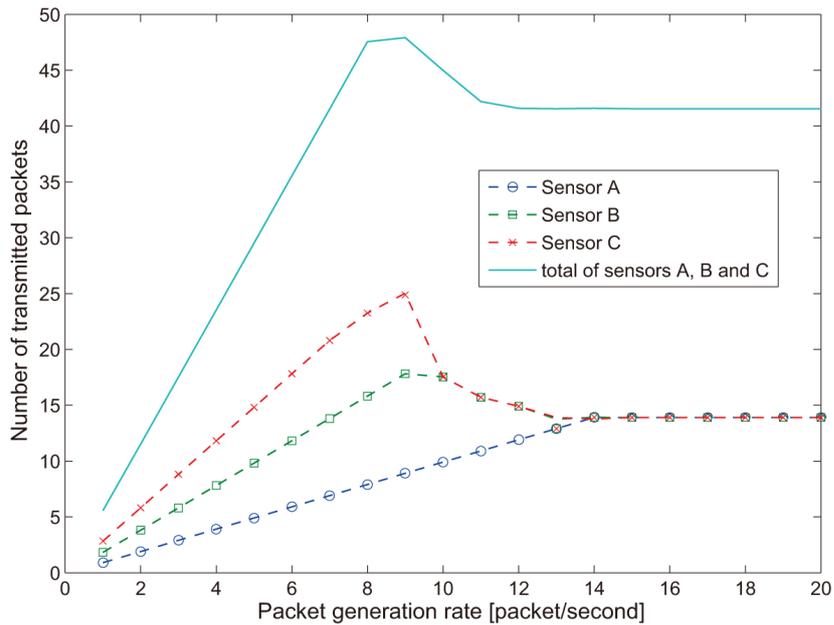


Figure 6. The number of successfully transmitted packets of all sensors.

successfully transmitted packets at sensors A, B and C increases when the packet generation rate (λ) increases. However, the number of successfully transmitted packets of sensor C starts decreasing when packet generation rate reaches 9 packets per second. The optimal packet generation rate has a slight difference between the theoretical and the simulation result. The reason can be explained that in simulation the packet generation rate is an integer value and increased by one. Furthermore, the reason why the number of successfully transmitted

packets of sensors C and B start decreasing when the packet generation rate is respectively 9 and 10, can be explained as follows. When the packet generation rate increases, the number of generated packets at each sensor increases. Moreover, since all sensors transmit a packet to the next sensor/coordinator, the number of packets at the sensor C increases considerably and all packets can't be transmitted in an unit time when the packet generation rate increases. Similarly, the sensor B can't transmit the packet of itself and the packet received from the sensor A when the packet generation rate reaches 10. When the packet generation rate is over 15, the number of successfully transmitted packets of all sensors is the same. In this scenario, the sensor A also can't transmit all its packets, the successful probability of all sensors is the same in all over $[0,1]$. Therefore, the number of successfully transmitted packets of all sensors is the same.

Figure 7 shows the number of remained packets of all sensors that isn't transmitted to the neighbor sensor or the coordinator in an unit time. The sensor C has the remained packet when the packet generation rate is over the optimal value. it reconfirms that the optimal packet generation rate is the maximum of packet generation rate with that all packets of sensors can be transmitted to the coordinator. The sensor A has the remained packet when the packet generation rate is over 15, it means that three sensors are in transmission in all duration $[0,1]$ and all sensors have the same number of successfully transmitted packets.

4.3. Optimal Packet Generation Rate Based on System Model

Any change in system model leads to the change in service time, however, in a system, the changeable factor is the payload. The optimal packet generation rate is calculated according to changing of payload and shown in **Figure 8**. The optimal packet generation rate decrease when the payload increases. The reason is that the service time increases when the payload increases meaning the maximal number of transmission packets decreases. However, the maximal throughput of system increases when the payload increases (**Figure 9**).

5. Conclusions

We have proposed the multiple hops scheme for WBAN and analyzed the performance of multiple hops WBAN with IEEE802.15.6 CSMA/CA protocol. The transmission probability, the successful probability as well as the number of successfully transmitted packets of all sensors were represented. Furthermore, the optimal packet generation rate with that all generated packets at sensors can be transmitted to the coordinator was obtained and the optimal packet generation rate based on system model was discussed. When the payload increases, the optimal packet generation rate decreases, whereas the throughput of system increases.

In this paper, due to the limited space on and/or in the body, we considered the WBAN with three sensors and one coordinator. However, this link was assumed to be independent to other sensors and links. The effect of other sensors that don't joint to this link, will be considered in the future work. Moreover, the noise was as-

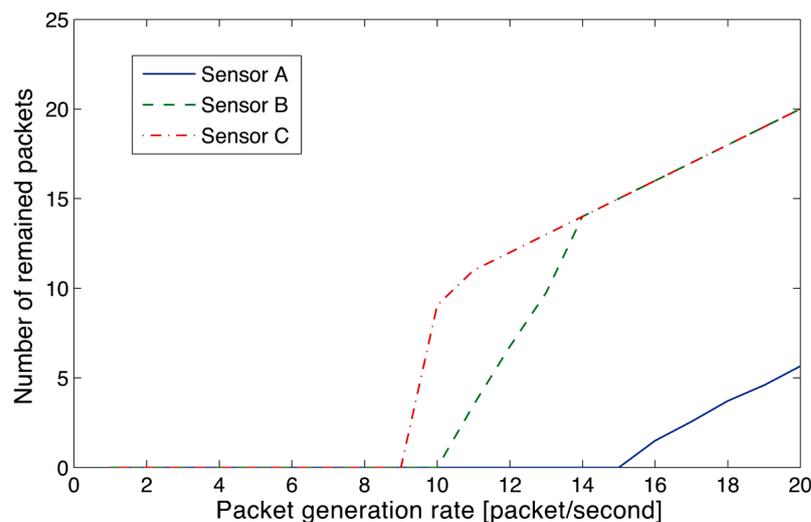


Figure 7. The number of remained packets.

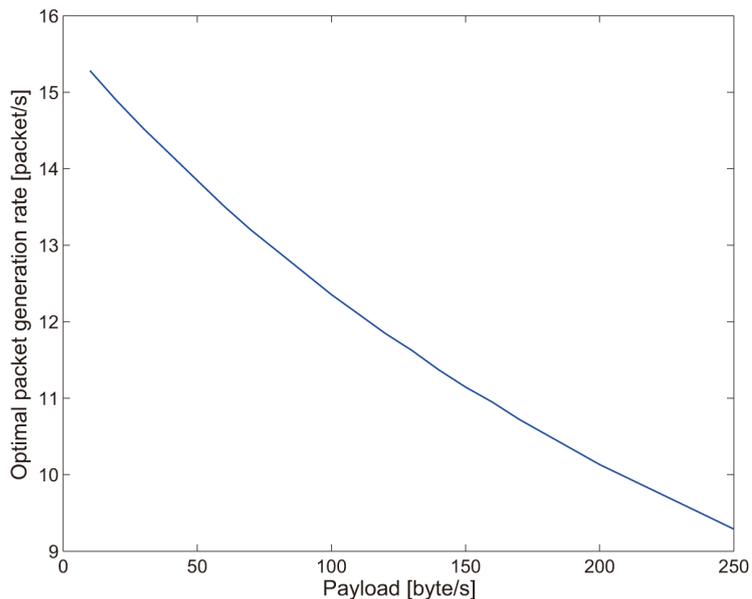


Figure 8. The optimal packet generation rate based on changing of payload.

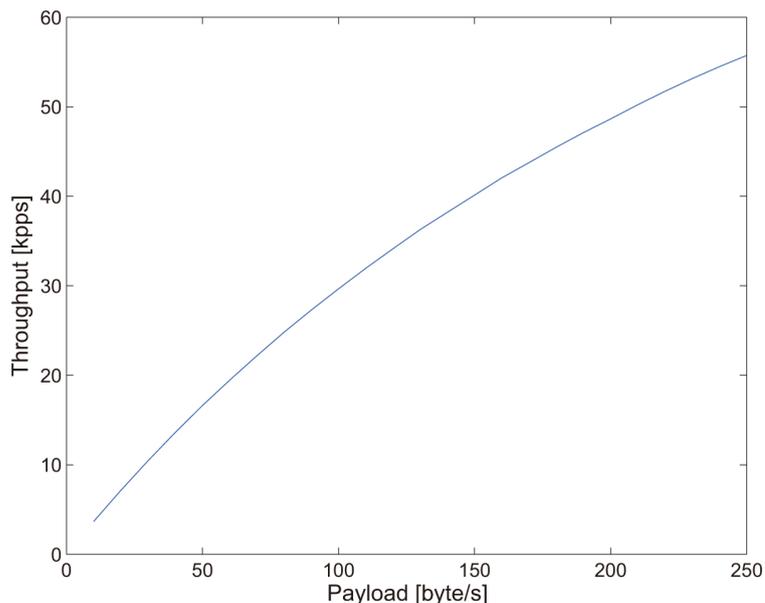


Figure 9. The throughput based on changing of payload.

sumed to be free and the distance between each sensors wasn't considered. We left them to the future work.

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