Enhancement of The Performance of Wireless Body Area Networks Through Cooperative Medium Access Control

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Abstract. In this paper, it is suggested a cooperative protocol based on two controller nodes. In the proposed protocol, the outer body master node as well as the belt master one are used for the avoiding the retransmitting operation via more than one sensor that increase the probability of the colliding, a master node works cooperatively to reduce BER, Power consumption in term of Duty cycle. We present an arithmetical model of the cycle of duty accompanied by the WBAN suggested protocol.

1. Introduction

A WBAN usually comprises a selection of lower power, made on a smaller scale, tending to spread prolifically or not, light appliances accompanied by wireless communicating abilities which work in the human body's proximity. Those appliances could be put in, on, or around a body, and are sometimes nodes of the wireless sensor type which has the ability to observe the functions of a human body as well as properties from the place around it [1-5].

The first point, a WBAN enables more than not used application and hence fresh potential markets according to a WSN, the second point, the design of theirs can be impacted by many issues which call for new typical examples as well as protocols. The variety of imagined applications, that extend from the medicine field (for example, effective signs observing, automatical drug delivering, etc.) to the surrounding, game, as well as immediate surrounding smartness areas, makes a group of technical needs accompanies with a broad varying according to anticipated performing metrics, as productivity or delaying, thus supple architectures as well as protocols are required. The major communication typical settlements seen as source can be considered as: IEEE 802.15.4 [6], IEEE 802.15.6 [7], as well as Bluetooth Low Energy [8]. IEEE 802.15.4 (they got it announced in the year 2006), assigns the materialistic as well as medium access control layers for communications of the short ranged wireless type, put for supporting the networks that are cheap, low-power, as well as low bit-rating. The IEEE
802.15.6 (they got is announced in the year 2012), was particularly made for wireless communicating
near, or in human bodies. In the end, Bluetooth Low Energy (BT LE) (they got it announced in the year
2010) can be the very low power consuming Bluetooth configuring, aiming at many apps for tiny as
well as low-cost appliances have their power from batteries of the button-cell type, like a wireless sensor.
Because of the very big number of existed criteria, it can be important to characterize the most feasible
settlement, relying on the application needs [1]. For the things that concern the major issues to get
accounted for in WBANs design, the wireless medium effect, the lifetime of a battery as well as the
cohabitation with wireless networks can be of essential importance this paper presents TMNCP as in [2]
to reduce BER, power consumption in term of Duty cycle. The main new contribution of this paper is:
1) An increasing cooperating communication is suggested which contains master nodes in
depending the collected information of a sensor on behalf of further sensors the on-body type.
2) The node of the belt master type functions the whole retransmitting as well as cooperating issues,
that decreases competing among sensors and reduces the possibility of collisions, and as a result,
developing energy competence.
3) The nodes of the master type can be instilled with dual transmitting and receiving devices, one
can be utilized to communicate with the sensors, and one cane be utilized to communicate among
master nodes.
Hence, it is not important to allow for the nodes of master type to have time within the time-
frame, as well as that decreases the vital sensor time very much, and decreases competing among
sensors. Besides, the TMNCP is not in need for a big changing in a WBAN 802.15.6 standard
besides the ability to be seen as a protocol of plug-and-play type.
4) The suggested protocol BER is derived via consid ering two kinds of channels, in another word,
small in scale and models the shadowing type. It is appeared as the following, the suggested
protocol has got decreased duty cycle, medium transmitting power as well as accomplish superior
energy competence.

The remainder of this document can be arranged as will be stated next: The next section described a
methodology of our design. Results are presented in the third section. The fourth one submits the
conclusion.

2. Methodology

2.1 The Architecture Model
A sample of an architecture of WBAN is displayed in the Figure 1 and Figure 2. The sensors have been
spread over the body surface for gathering the information of health, the sensors transfer the information
to the coordinator to be analyzed. In a system of WBAN built on the topology of one-hop star, all of the
sensors transfer their information towards the coordinator. In a scenario like that, the main reasons of
the losses in power in a WBAN are, retransmitting operation because of fade and colliding, overhearing,
idle listening, traffic fluctuations, as well as protocol over-head, the fade and colliding and idle listening
could be bypassed only in part or completely via using two masters-slave topology [2].

In the document, the architecture of two masters-slave can be suggested. A node of the master type
can be set over the body, like some node taken on every side of a belt, that could be named OBN. The
second node of the master type performs like a monitoring device besides having the ability to take
information from the nodes of the sensors (slaves) the same way the held node does, and it can be pointed
out like the OMN, that is the outer master node. Due to the body moving, the spaces among the two
nodes of the master type as well as the sensor one alter [2].
A few sensors might be positioned not close from the OMN if we made a comparison between it and OBN and the other way around. So, a few sensors might have superior channel quality regarding OMN towards OBN.

### 2.2 TMNCP’s Communication Model

The suggested protocol considers the concept of ARQ, it functions within cooperating fashion, just like it is mentioned below [2]:

Within initial phase, the node of the sensor transmits information towards the nodes of the master type (outer nodes as well as on-body ones). In the other one, OMN tests the taken information for determining if it was taken correctly; after that the OMN transfers an ACK positive in the reverse direction, besides OBN comes the information off which was taken out of a sensor, just like it is displayed in Figure 3. If not, the OMN transfers NACK towards the OBN, that re-transfers the information which was taken from the sensor towards the OMN and after that merges the information of the signal of the first and other phases by MRC which is Maximal Ratio Combining. The goals of the achievement can be briefed as mentioned below [2]:

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**Figure 1.** WBAN network architecture with two master nodes [2].

**Figure 2.** System model for WBAN cooperative communication [2].
1) Develop the accuracy of the taken information: if the signal cannot be taken accurately at OMN, after that OBN re-transfers information taken out of a sensor towards OMN, besides it merges the taken information, hence developing information goodness.

2) Efficient utilize of energy at the sensors and the OBN: if the information can be taken correctly at OMN, OBN is not in need to re-transfer information of the sensors that is occurring in conventional WBAN communicating system, hence decreasing the power consuming of OBN. If the information taken at OMN has been damaged, the OBN re-transfers an extra reduplication for information towards OMN not include more than one sensor within retransmitting operation, that can be considered as the most important reason of the draining of sensor energy of WBAN.

2.3 Power Analyzing And Duty Cycle Of CSMA / CA Built On IEEE 802.15.6

Within this, DC or duty-cycle is addressed as well as power for the conventional CSMA/CA topology of slave-master type built on IEEE 802.15.6. The medium transmitting power can be linked in a direct way to the duty cycle. DC equals to needed while the rate of the RF active time towards time of sleep multiplies the factor. $1/CPER$. DC can be shown as it is [9]:

$$\text{DC} = \frac{T_{\text{active}}}{T_{\text{sleep}}} \left(1 + PER\right) \quad (1)$$

where $T_{\text{active}}$ is the RF activity time, which is given as [9]:

$$T_{\text{active}} = T_{\text{on}} + T_{\text{CW}} + T_{\text{data}} + T_{\text{ACK}} + 2T_{\text{SIFS}} + 2T_a \quad (2)$$

$T_{\text{CW}}$ is average contention time and it is given as:

$$T_{\text{CW}} = 0.5 \cdot CW \cdot T_s \quad (3)$$

The required time to send a data is given as [9]:

$$T_{\text{DATA}} = T_P + T_{\text{PHY}} + T_{\text{MAC}} + T_{\text{BODY}} + T_{\text{FCS}} \quad (4)$$

The acknowledgment sending time is given by:

$$T_{\text{ACK}} = T_P + T_{\text{PHY}} + T_{\text{MAC}} + T_{\text{FCS}} \quad (5)$$

The average probability of error at the packet level at each hop is given as [10-11]:

$$\text{PER} = 1 - (1 - BER)^{P_{\text{ingth}}} \quad (6)$$

The DC is given as [2]:

$$\text{DC} = \frac{T_{\text{on}} + T_{\text{CW}} + T_{\text{data}} + T_{\text{ACK}} + 2T_{\text{SIFS}} + 2T_a}{T_{\text{sleep}}} \times \left(2 - (1 - BER)^{P_{\text{ingth}}}\right) \quad (7)$$

The factor, $(2 - (1 - BER)^{P_{\text{ingth}}})$, is taken into account, which shows how the BER influences DC. DC and the average transmission power are affected directly by the factor $(2 - (1 - BER)^{P_{\text{ingth}}})$.

The average transmission power, $P_{\text{av}}$, is obtained via multiplying DC, $V_{dd}$, and $I_{\text{act}}$, where $V_{dd}$ is the radiofrequency (RF) of the module supply voltage, and $I_{\text{act}}$ is RF active average current [12].

$$P_{\text{av}} = DC \times V_{dd} \times I_{\text{active}} \quad (8)$$

The major goal of TMNCP is minimizing retransmissions’ total via the sensor nodes via decreasing BER, that has got an immediate impact on the duty-cycle as well as medium transmitting power of a node. And the suggested protocol’s BER has got two sections, in another word, 1) immediate
transmitting among the nodes of the sensor type and ones of the master type, as well as 2) cooperating transmitting, that happens among the master ones. The suggested protocol’s BER can be given as [2]:

\[
BER_{\text{DPSK}}^{\text{TMNCP}} = \left( BER_{S,\text{DBN}} \cap BER_{S,\text{OMN}} \right) \cup \left( (1 - BER_{S,\text{DBN}}) \cap BER_{S,\text{DBN}} \cap BER_{\text{DBN,OMN}}^{\text{coop}} \right)
\]  
(9)

The event of the two phases and the events in each phase are exclusively independent, so we can re-write (9) as [2]:

\[
BER_{\text{DPSK}}^{\text{TMNCP}} = \left( BER_{S,\text{DBN}} \cdot BER_{S,\text{OMN}} \right) + \left( (1 - BER_{S,\text{DBN}}) \cdot BER_{S,\text{DBN}} \cdot BER_{\text{DBN,OMN}}^{\text{coop}} \right)
\]  
(10)

The modulating scheme utilized for IEEE 802.15.6 standard can be DPSK [13]. So, the BER over node \(i\) because of transmitting out of node \(i\) can be obtained like[2]:

\[
BER_{\text{DPSK}} = Q \left( \frac{1}{2} e^{-\frac{(Y_{\text{i,j}} - |a_{i,j}|^2)}{2}} \right)
\]  
(11)

where \(Y_{\text{i,j}}\) can be SNR or signal to noise rate among sensor \(i\) and sensor \(j\); \(|a_{i,j}|^2 = d_{ij}^v\) can be the wireless channel gaining; \(d\) can be the space among every couple of number of nodes; as well as \(v\) can be the exponent of path loss, and \(Z\) can be symbolized by the model of the shadowing type and can be component Gaussian random variable accompanied by zero variance and mean equals \(\sigma_i^2\). Within the study, we have got a couple of channels for communicating, in another word, sensors to the node of OBN, that is called as on body communicating channel. After that, the other potential path can be more than one sensor to OMN as well as OBN to OMN, that is called off body communicating channel. On body communicating, that can be the initial channel symbolized as a model of shadowing qualities, and on body towards outer appliance communicating, that can be the other potential channel, and it can be symbolized to be the Quasi-static channel model [14]. Considering DPSK’s BER, that can be shown within (11), it is possible to write (10) again as [2]:

\[
BER_{\text{DPSK}}^{\text{TMNCP}} = \left( e^{-\frac{1}{2} Y_{\text{SOBN}} x_{\text{S,OMN}}^2} + e^{-\frac{1}{2} Y_{\text{S,OMN}} x_{\text{S,OMN}}^2} \right)
\]  
(12)

where \(Y_{\text{SOBN}}, Y_{\text{S,OMN}}\) and \(Y_{\text{DBN,OMN}}\) can be the signal to noise rates among OBN and sensors, sensors and OMN, besides OBN and OMN in the order given. \(Z_{\text{S,OMN}}\) can be the channel gaining among the OBN and the sensors, that can be symbolized by a model of the shadowing qualities. Both of \(X_{\text{S,OMN}}^2\) as well as \(X_{\text{DBN,OMN}}^2\) can be expressed as the channel gaining from the sensors towards OMN as well as from OBN towards OMN, in the order given, that can be symbolized to be the Quasi-static model, besides its ability to be expressed as exponential random variable accompanies by an average, \(|a|^2 = d^v\), and a variance of unity. Via the insertion of the (12) in (7), after that the insertion of the new DC in (8), we have the ability to get the medium transmitting power of the suggested protocol.

### 2.4 Numerical Outcomes and Discussion
Within the subsection, the TMNCP protocol performing can be estimated according to BER, duty-cycle, and medium transmitting power. Within this estimation, it is presumed the similar SNR out of sensor
towards OBN, and OBN towards OMN, sensor towards OMN, as spaces among nodes have been presumed as variant.

Figure 4 illustrates an BER comparing of the instant transmitting 802.15.6 standard as well as TMNCP to variety normalized spaces of \( d_{SOBN} = \{0.5, 0.75, 1\} \) as well as \( d_{SOMN} = \{0.5, 0.75, 2\} \) on differing SNR, in another word, \{-5, -4, -3…, 5\}, the significant outcomes that is notices in the related figure can be briefed as mentioned below:
1. Instant transmitting has got less performing comparing with TMNCP, as BERs seems minimal to TMNCP.
2. At \( d_{SOBN} = 5dB \), BER can be considered as high comparing with \( \sigma_{SOBN} = 7dB \) as well as \( 9dB \) to TMNCP.
3. TMNCP's BERs declined as the spaces among the nodes became less.
4. For the high SNR as well as at \( \sigma_{SOBN} = 9dB \), TMNCP's BER has got superior performing comparing with the instant transmitting.
5. At low SNR as well as at \( \sigma_{SOBN} = 5dB \) as well as \( 7dB \), BER of instant transmitting approaches TMNCP's BER. Anyway, at low SNR as well as at \( \sigma_{SOBN} = 9dB \), the TMNCP's illustrates superior performing comparing with the instant transmitting.

Figure 5 illustrates comparing for DCs of instant transmitting and TMNCP to variety-normalized spaces of \( d_{SOBN} = \{0.5, 0.75, 1\} \) as well as \( d_{SOMN} = \{0.5, 0.75, 2\} \) on SNRs of \{-5, -4, -3…, 5\}, the significant outcomes which we can notice within the figure can be briefed just like how it is mentioned below:
1. Instant transmitting's DCs have been bigger than the TMNCP's DCs, and the reason is that the suggested protocol has got superior performing according to BER than the instant transmitting that instantly impact and decrease the DC.
2. As the nodes of the sensor and master types have been near one other, duty-cycles have been decreased owing to the space among the nodes being smaller, that decreased the BER, which yield an instant reducing within duty-cycle.
3. Bigger parameters of the shadowing quality decrease DCs, and the reason is that the shadowing variety developed the linkages' quality and decreased BER, that as a result decreased the DCs.

3. Results
Within the section, the performing of TMNCP protocol which has been submitted in the above-mentioned sections was estimated in terms of bit error rate, duty cycle and power consumption utilizing TMNCP protocol. During the estimation, it is presumed the similar SNR between sensors towards OBN, and OBN towards OMN, sensors towards OMN, as spaces among every node are presumed variant.

Figure 5 illustrates the BER's comparing among instant transmitting and utilizing TMNCP for variance normalized spaces of \( d_{SOBN} = \{0.5, 0.75, 1\} \) as well as \( d_{SOMN} = \{0.5, 0.75, 2\} \) over varying SNR, SNR = \{-5, -4, -3…, 5\}, sleeping time 3s. The significant outcomes seeming within this figure can be briefed as the following:

The instant transmitting mode has smaller performing comparing with the cooperative transmission mode, where BERs are less over cooperative transmission mode using TMNCP. The duties cycle of direct transmission is bigger than TMNCP's duty cycles due to the suggested protocol has superior performing and BER compared to instant transmissions that instantly effect as well as decrease the duty cycle. As the sensors as well as master nodes near to one other, those duty cycles reduce owing to space among nodes is smaller that reduce the BER which effect directly on the duty cycle and reduce it. Larger shadowing parameter, less duty cycle because shadowing variance improve link quality and reduce BER which consequently reduce the duty cycle. At \(-2dB\) an increased is achieved by 6.5% at \( \sigma_{SOBN} = 9dB \) and distance from sensor to outer master node 0.75 and on body master node is 0.5.
Figure 3. WBAN duty cycle comparison against sleeping time 3s and SNR for \( \eta = 2 \).

Figure 4. The TMNCP's BERs decrease while the spaces among nodes decrease. At 5 dB BER is 10^-4 for non-cooperative system, for proposed protocol the BERs are 10^-6, 10^-11 and 10^-23.

Figure 4. DPSK BER comparison against sleeping time 3s SNR for \( \eta = 2 \).

Figure 5 illustrates the comparing of medium power consumption over SNR. It can be considered as obvious that the medium power consumption can be smaller utilizing the suggested protocol. The medium power consumption has got bigger reduction as spaces among nodes reduce and shadowing varying increases. At -3 dB the improving accomplished via the suggested protocol is 7.8% at a shadowing variance 9 dB.
Distance SOMN and OBNOMN set to 3 meter and checking the effect of duty cycle, BER, and power consumption. At $-2 \, dB$ an increased is achieved by $5.8\%$ at $\sigma_{DBM}^2 = 9dB$ and distance from sensor to outer master node 0.75 and on body master node is 0.75. as shown in Figure 6.

Figure 6. WBAN duty cycle comparison against sleeping time 3s and SNR for $\eta=2$.

Figure 7 The TMNCP’s BERs decrease as the spaces among nodes decrease. At 5 dB BER is $10^{-4}$ for non-cooperative system, for proposed protocol the BERs are $10^{-6}$, $10^{-11}$ and $10^{-23}$. 
Figure 7. DPSK BER comparison against sleeping time 3s SNR for $\eta=2$.

Figure 8 illustrates the comparing of medium power consumption over SNR. It can be considered as obvious that the medium power consumption has been smaller utilizing the suggested protocol. The medium power consumption has got bigger reduction as spaces among nodes reduce and shadowing varying increases. At -3 dB the improving accomplished via the suggested protocol is 9.6% at shadowing variance 9 dB.

Figure 8. WBAN Power Consumption comparison against sleeping time 3s SNR for $\eta=2$.

4. Conclusion
In the document, it has been submitted a kind of TMNCP which can be developed accuracy, medium transmitting power, and energy competence belongs to WBANs. TMNCP has been doing the transmission for the information over two separate routes along with helping both nodes of master type. It can be functioned in a couple of phases : broadcasting that by it, on body sensor transmits the information towards the nodes of the master type, and the other phase in which the nodes of the master type substitute information in a cooperative way taken from the sensor. TMNCP gave the ability to two
nodes of the master type in WBAN mechanisms that helped the sensors re-transmit the damaged information and so improved the energy competence of theirs. The outcomes illustrated that the suggested protocol can be more superior than instant transmitting as the spaces among nodes can be decreased as well as the shadowing varying can be raised. It has been noted as well that the medium transmitting power has been reduced via 0.21 factor as TMNCP protocol has been utilized. Furthermore, it has been shown that the TMNCP's energy competence related to the suggested protocol of [15] can be developed by 0.69's factor. In addition, the TMNCP's BER can be decreased via a factor of four comparing with the instant transmitting.

For the works in future, the suggested protocol will be analysed utilizing a network related to cognition which permits two various sensor nodes for using dynamic spectra allocating which decreased competing on the single spectra.

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