Interference-Aware MAC Scheduling and Admission Control for Multiple Mobile WBANs used in Healthcare Monitoring

Judhistir Mahapatro, Sudip Misra, *Senior Member, IEEE,* Manjunatha Mahadevappa, *Member, IEEE,* and Nabiul Islam

***Abstract*—In this paper, we address the problem of interference when multiple TDMA-based WBANs come in the proximity of one another. We propose a simple solution that creates common non-conflicting schedule between these interfering WBANs. Our proposed scheme allows the reuse of maximum possible time slots among WBANs that are two-hop neighbors of one another. A flow admission control scheme is applied to control the flows during the period of interference. We show that the percentage of flows admitted due to flow control decreases with the increase in the network size and flow rate. We simulated a scenario where WBANs move randomly within a simulation area with a certain speed and meet at a particular point. We show that the Signal to Interference Noise Ratio (SINR) value of WBANs changes as long as they are within the transmission range of one another. Also, we show that the exchanges of common schedule (which is dependent on the number of times the SINR value drops below the threshold) are required in order to improve the packet delivery ratio in WBANs.**

***Index Terms*—WBAN, Interference, TDMA**

I. Introduction

WBANs have recently gained popularity due to their ability in providing innovative, cost-effective, and user-friendly solution for continuous monitoring of vital physiological parameters of patients, especially those who suffer from chronic and serious diseases such as cardiovascular diseases (CVDs), diabetes, and so on. They can be deployed in elderly persons for monitoring their daily activities and chronic medical conditions. In a WBAN, physiological parameters are aggregated from various implanted and worn-on devices that are attached in-body and on-body respectively, and are sent to remote medical servers for analysis [1].

The development of short-range transceivers makes patient monitoring applications accomodate more number of monitoring devices in a confined space. There are short-range transceivers designed for such purpose, e.g., one with 1 meter range is available in [2].

The wireless technologies are widely accepted in different domains such as military, industry automation, and entertainment. The evaluation of performance and suitability of low power Wireless Personal Area Network (WPAN) is specified in the IEEE 802.15.4 standard for medical applications in [3]. This paper reports the results of a simulation-based study for a network having a ring topology, where 16 transmitters are placed on the circumference of the circle with a certain radius from the center and a receiver is placed at the center of the circle. The study of performance evaluation is limited to 16 transmitters and do not consider the scalability of the network nodes with the same topology.

In the monitoring system, we considered patients carrying wearable systems and can move anywhere in the hospital. Pulse oxymeter is an example of one such wearable system which can measure the amount of oxygen present in the blood. Medium access by the devices in such wearable systems is one of the important research challenges due to the shortage of available channels and bandwidth in the medical band. It is observed that slot-based MAC protocols are suitable for improved operation and performance, since such protocols require no additional overhead and data load is uniform across the nodes. In the literature, most of implementations of WBAN use the IEEE 802.15.4 standard or its variant for low power consumption [4] [5] [6]. It considers a star topology, where each sensor node sends traffic to the coordinator (controller) in their own slot time. In [5], Li and Tan proposed a TDMA-based MAC protocol for a wearable system having few sensor devices such as

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pulse oxymeter and a coordinator. The coordinator of the wearable system is responsible for scheduling and initiation of transmission of the end devices.

WBANs use the 2.4 GHz ISM band for their operation. Since the ISM band is unlicensed, several other wireless devices based on Wi-Fi, Bluetooth, and other Body Area Networks (BANs) share the same frequency band, thereby causing fairly high possibilities of interference. The effect of interference is very serious for patients equipped with BANs, because the devices typically monitor the critical conditions involving instruments for measuring ECG, EEG, and EMG. The seriousness is such that the misinterpretation of signals due to interference can lead to the death of a patient [7]. This *motivated* us to investigate the problem of interference in the presence of multiple WBANs. We consider a scenario where there are multiple WBANs, as in a hospital, where the patients' beds are adjacent to one another with little inter-bed spacing. In addition, the users could move anywhere in the hospital. It is obvious that the wireless channels in WBANs may overlap with one another, thereby degrading the performance of these networks.

In this paper, we specifically explore the problem of network interference between WBAN equipped patients. This happens when two or more WBANs come in the proximity of one another and stay for longer time. As shown in Fig. 1, two TDMA-based WBANs are within the interference range of one another. Among different types of interference such as co-channel interference, and adjacent channel interference, network interference is predominant [8]. Let us consider an example of two aged persons carrying BANs, with the devices measuring their critical physiological parameters. Let us consider the case in which they live in the same house or an old-age home and talk to each other for long duration of time while sitting together. In this case, both BANs send false information to the medical server. The situation becomes even worse if the BANs carry life saving actuators such as glucose actuators, which pump the correct dose to the diabetics if the glucose level goes beyond or below normal. The coordinators of the WBANs observe the degradation in the signals they expect to receive. They adaptively increase their power level to combat such situations. However, doing so leads to an increase in energy consumption by the nodes. This power control mechanism at nodes may not help much when there exists a large number of interfering nodes in a network.

The mathematical analysis of bit error rate (BER) and packet error rate (PER) for different coexisting networks such as between ZigBee and Wireless Local Area Network (WLAN), ZigBee and Bluetooth, and Bluetooth and WLAN have been reported in [9]. However, in some scenarios, the PER analysis has considered only a single node of a network interfering with the nodes of other networks. Also, there has not been any work related to the PER analysis of two coexisting low power networks such as between ZigBee and ZigBee. Also, such studies have never considered the scalability of networks.

To mitigate interference, several solutions (e.g., [10], [11], [12]) exist in the literature in the context of general Wireless Sensor Networks (WSNs), cellular networks and other wireless networks. These solutions are embedded either in the software or hardware. In [10], the interfering signals from various links of the WSN are scheduled at different times. The typical hardware solution is to use dual radios, one for IEEE 802.15.4, and the other for IEEE 802.11, which is used to mitigate interference [11]. MIMO technology has been proven useful in mitigating interference in cellular networks [12].

None of the above referenced solutions are applicable for WBANs due to their unique features such as unpredictable mobility, energy constraint, and miniaturization of devices. Also, the constraint of low power consumption makes it inefficient to adopt the power control strategy, which is used in cellular networks [13]. We addressed this problem in our previous paper [14] by enabling two or more WBANs cooperating between themselves and having them agree on a common schedule, rather than sending data independently. If they agree with a common schedule, there might be a case that devices attached to a WBAN wait for relatively longer time than those devices which have large traffic or they are in large numbers attached to other WBANs. In this case, we make the schedules interleave among themselves, so that the average latency per node is minimized.

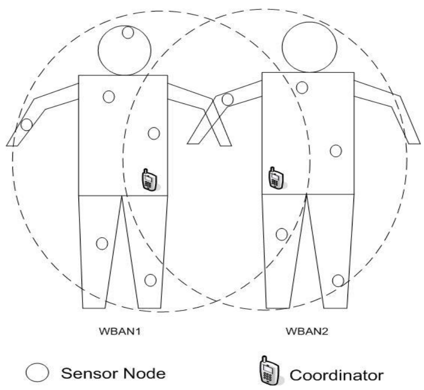


Fig. 1: Two WBANs within the interference range of one another

A. Contribution

The research contributions of this work are as follows.

- We have designed an interference framework for WBANs. The framework consists of an interference helper and various models for the operational functionalities of different layers in the protocol stack.
- We have designed a mechanism for the creation of a common non-conflicting schedule for WBANs interferes with one another. The novelty of the proposed approach is that it produces fair average waiting time for all the WBANs.
- We have proposed a simple algorithm which decides when to exchange schedules in the presence of interference.
- We proposed a scheme for the simultaneous usage of slots by invoking non-interfering WBANs which are not exposed by data transmissions from other WBANs. Eventually, this scheme increases the overall throughput in the network. Our scheme is capable of computing the maximum possible number of slots that can be reused by WBANs, which are two-hop neighbors.
- We derive a condition to control admission of flows of TDMA-based WBANs. Such a condition is checked when new flows want to join the network interference graph. The network interference graph or the contention graph of WBANs is dynamically generated, when they detect that their channels overlap.

The rest of the paper is organized as follows. Section II discusses the proposed framework to handle interference in the network of WBANs. Section III discuses the proposed protocol which creates a common schedule for the WBANs. Section IV discusses the proposed algorithm which can decide when to exchange the schedules. Section V discusses the contribution regarding the reuse of time slots and an admission flow control mechanism for WBANs, which interfere with one another. Section VI presents the simulation results. Finally, Section VII concludes the paper.

TABLE I: Acronyms and symbols

Acronyms and symbols	Meaning
AWT	Average Waiting Time
CD	Cycle Duration
CAWT	Combined Average Waiting Time
WT	Waiting Time
EWT	Excess Waiting Time
FAWTF	Fair Average Waiting Time Factor
NAWT	New Average Waiting Time
SIR	Signal-to-Interference Ratio
TDMA	Time Division Multiple Access
WBAN	Wireless Body Area Network
T_i	Amount of time is allotted to i^{th} node in a WBAN
τ	Time for mini slot in the superframe
T	Time for each data slot in the superframe
η_i	Number of slots for i^{th} node
T_{pd}	Propagation delay between two antennas
WT_i^j	The WT of the i^{th} node of the j^{th} WBAN
SIR_a	The calculated SIR value at the coordinator 'a'

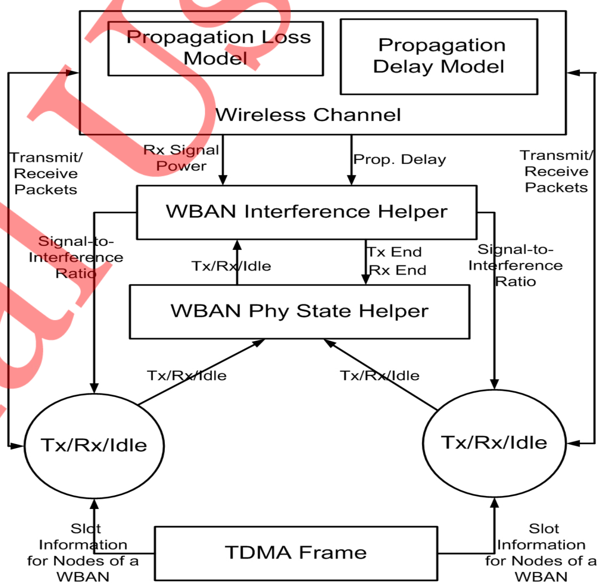


Fig. 2: Interference Framework

II. Interference Framework for WBAN

The proposed framework for interference in WBANs consists of two different types of network nodes — coordinator and end device. Additionally, there are other components such as the device state model, the interference helper, and the interfaces interconnecting them, as shown in Fig. 2. The state model keeps track of complete information about a node that is in one of the states at different instants of time. These states include Transmit (Tx), Receive (Rx), and Idle. The other models include propagation loss and delay. The former represents the amount of power loss in the air due to the environment condition, signal fading, and obstacles. The latter represents the amount of time the signal takes to travel at the receiver over the wireless medium. The helpers are designed to handle a complete set of functionalities related to a particular task. There are two such helpers:

1) *WBAN Interference Helper*: It records the duration for which a node receives data packets from another node and calculates the SIR value at the receiver. It notifies this SIR value to the MAC layer. The MAC layer takes control decisions according

to the obtained value.

2) *WBAN Phy State Helper*: It keeps track of the current state of all the network nodes. The helper notifies the current state of the node to the physical layer device (i.e., the transceiver), and the interference helper.

A. Propagation Loss Model

Transmission power is the average power consumed by the antenna of a transceiver to transmit the signal to a distantly located receiver. In WBANs, the nodes are closely placed (0.1 - 2.0m). The required transmission power in the antenna is less than one milliwatt. The radio devices are based on IEEE 802.15.4, and use the maximum transmission power of 1 mW (0 dBm). In our framework, we use Frii's propagation loss equation [15] to calculate the reception power at the receiver, which is given below.

$$Power_{rx} = Power_{tx} \times Gain_{tx} \times Gain_{rx} \times (\frac{\lambda}{4\pi d})^{\eta} \quad (1)$$

where $Power_{rx}$ and $Power_{tx}$ represent the power received and transmitted, respectively, $Gain_{tx}$ and $Gain_{rx}$ represent the antenna gains of transmitter and receiver, respectively, λ represents the wavelength, and d represents the distance between two antennas. η is the signal attenuation factor ($\eta \in [2, 4]$) and its value varies between 2–4 for free space to indoor. The minimum received power level for a coordinator to decode the signal successfully is assumed to be -70 dBm. The nodes in a WBAN transmit with a transmission power of -5.0 dBm.

B. Propagation Delay Model

In wireless communication, the transmission of signals take place in the free space. The radio signals travel in the air at a speed equal to the speed of light. The propagation delay in such mode of communication is defined as the amount of time a signal (sent by a transmitting node) takes to arrive at the receiving node. The propagation delay model is presented in the equation below:

$$T_{pd} = \frac{d}{S}$$

where, T_{pd} and d represent the propagation delay and the distance between two antennas, respectively. S is the speed of light (3×10^8 m/s).

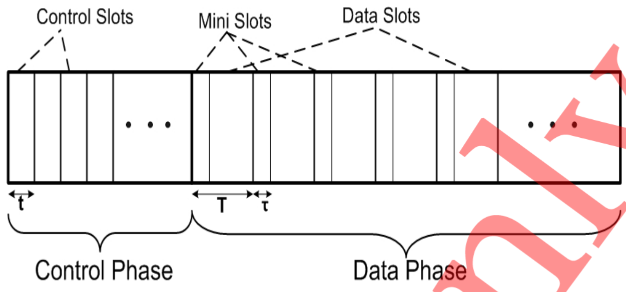


Fig. 3: Frame format of MAC protocol

C. Superframe of TDMA

We have discussed in Section I that the TDMA MAC protocol and its applicability in medical wearable systems. The superframe format of the TDMA MAC protocol is shown in Fig. 3. It is divided into two phases: (1) *Control phase*: In this phase the coordinator initiates a frame by broadcasting a beacon signal. Upon receiving the beacon, the sensor nodes seek the allocation of the required number of slots in the reply message. The coordinator assigns the number of available slots to the nodes by an allocation strategy. (2) *Data phase*: In this phase the sensor nodes transmit the data packets from the queue to the coordinator in the slots allotted to them. The mini slot, which is a small fraction of time in the data slot, is used by the coordinator to stop the scheduled transmissions from the nodes. The sensor nodes listen to this slot for the beacon from the coordinator. The beacon contains a binary digit, '1', for the node to transmit, and, '0', for the nodes to stop further transmissions.

D. Signal to Interference

In wireless communication systems, the interference range of any node is assumed to be equal or more than its transmission range. Nodes may fail to communicate with the desired receiver if there exists any other node within the transmission range that also attempts to transmit at the same time. Therefore, a pair of nodes can transmit and receive within the transmission range. Concurrently, transmissions from any other node are treated as interference at the receiver. We intend to present the interference scenario as shown in Fig. 1. It arises due to the existence of two WBANs in the range of one another. Let us consider two WBANs ('a' , 'a_{11}') and ('b' , 'b_{11}'), where 'a' and 'b' are the coordinators, and 'a_{11}' and 'b_{11}' are the sensor nodes. The reception power at the coordinator according to the radio propagation loss model with distance '$d_{(a,\ a11)}$' between the coordinator 'a' and the sensor 'a_{11}' is given as:

$$P(a) = K \ . \ \frac{Power_{tx}}{(d_{(a,\ a11)})^{\eta}} \quad (2)$$

where, K is a constant that depends on the antenna. Similarly, for the coordinator 'b', the value of P(b) can also be calculated. The interfering signal power from 'b_{11}' received at coordinator 'a' is denoted as P(a_{11}). Similarly, the interfering signal power from 'a_{11}' received at coordinator 'b' is denoted as P(b_{11}). The SIR, which is the ratio of the received power from the desired transmitter to the received power from the interfering source, is computed as:

$$SIR_a = \frac{P(a)}{P(b_{11})} \tag{3}$$

Similarly, $SIR_b = \frac{P(b)}{P(a_{11})}$.
If there exists 'n' number of interfering sources, then SIR at coordinator 'a' for the k^{th} source can be calculated as follows.

$$\frac{P_k(a)}{N + \sum_{i \neq k}^{n} P_i(a)} \tag{4}$$

where the noise floor N = ($\kappa \times T \times B$)×Δ, and κ, T, B, and Δ represent the Boltzmann constant, system noise temperature, bandwidth, and noise figure, and their values are 1.3803e-23, 290 Kelvin, 2e+6 Hz, and 7 dBi, respectively.

We consider the transmission power for all sensor nodes of WBANs to be equal. Also, we assume that the transmission and interference ranges for the network nodes are equal.

III. Creation of a Common Schedule

Let us suppose multiple WBANs come close to one another. This leads to more than one patient carrying WBANs coming in the proximity of one another. In such a scenario, we compute the common schedule by exchanging their own schedules, as explained in detail below.

1) Each WBAN calculates the average waiting time for its nodes, and it is computed by using the following approach.

   Let *AssignTime* be the time duration for which a node can transmit its traffic. It is defined as the number of slots given to the node multiplied by the time of each slot. This is shown in (5). The number of slots for a node could be based on the amount of traffic it generates. Usually, the time of each slot is fixed.

$$T_i = (T + \tau) \times \eta_i \tag{5}$$

   The complete CD of TDMA of the WBAN is computed as follows.

$$CD = \sum_{i=1}^{n} T_i \tag{6}$$

   where i = 1, ..., n, and 'n' is the number of nodes in a WBAN.

   The AWT of the WBAN is computed as follows.

$$AWT_j = \frac{\sum_{i=1}^{n}(CD - T_i)}{n} \tag{7}$$

   where j = 1, ..., m, and 'm' is the number of WBANs.

2) Each WBAN's shedule can either be merged serially or be interleaved. In either case, the WT of the i^{th} node of the j^{th} WBAN is calculated as follows.

$$WT_i^j = \sum_{j=1}^{m}\sum_{i=1}^{n} T_i^j - T_i \tag{8}$$

   The CAWT in common schedule is computed as follows.

$$CAWT = \frac{\sum_{j=1}^{m}\sum_{i=1}^{n} WT_i^j}{p} \tag{9}$$

   where p = $\sum_{j=1}^{m} n_j$, and 'n_j' is the number of nodes in j^{th} WBAN and 'p' is the number of nodes participating in the common schedule.

3) The above schedule does not always produce fairness in waiting time for all nodes, because a WBAN with a few number of nodes has to wait relatively longer for the completion of data transmission, compared to that of a WBAN which carries large number of nodes and/or has larger data traffic to send. So, in order to give fair value to all participating WBANs, some nodes of the deprived WBANs are allowed to repeat the transmission again in a complete common schedule duration. We compute this as given in Equation (10).

   Each WBAN computes the duration for which it has to wait in common schedule compared to its own schedule, and it is computed as:

$$EWT = \frac{CAWT}{AWT_j} \tag{10}$$

   The FAWTF for all WBANs is computed as follows.

$$FAWTF = \frac{EWT}{p} \tag{11}$$

4) The NAWT of a WBAN is calculated and it is given in Equation (12).

$$NAWT = FAWTF \times AWT_j \tag{12}$$

   The deprived WBAN repeats its transmission again after $NAWT$ of time in a complete cycle of the common schedule.

IV. Exchange of TDMA Schedule

Interference occurs due to external nodes concurrently transmitting within the transmission range of a sender, while its data transmission is underway. Eventually this reduces the SIR value [16]. We assume that the co-ordinators are not resource-constrained. Therefore, the coordinator can continuously compute and monitor the SIR value of the reception signal. If the coordinator finds the SIR value below a threshold, it then calculates the probability of being interfered with external WBANs. The interference (or victimization) probability of the coordinator is computed as follows:

$$Pr = \frac{x}{y}$$

where

x : Number of times the SIR value of the coordinator below its threshold value, and

y : Total number of times the coordinator calculates SIR.

The WBAN with high victimization probability initiates the exchange of its schedule with other interfering WBANs. The psuedo-code of the algorithm is given in Fig. 4.

V. Simultaneous usage of Slots among WBANs

As we notice, when two or more WBANs follow the same common schedule, there might be a case where more than one WBAN can send data, as illustrated in Fig. 5. While the nodes of WBAN 'A' send their data, the nodes of WBAN 'C' can also send data, because WBAN 'C' is not interfered by WBAN 'A'. So, WBANs 'C' and 'A' can together use the same slots to send data, and, hence, the total throughput of the network increases. In essence, the WBANs can simultaneously use the slots, whenever possible.

In order to compute the maximum possible number of slots that can be reused by a WBAN, we consider the number of slots for the given bandwidth of a channel to be 'N'. The nodes of the WBANs can have successful transmissions by satisfying the condition that the total number of slots of all the interfering WBANs should be less than or equal to 'N'. Let the number of slots allocated to WBANs 'A','B' and 'C' be denoted by n_A, n_B and n_C, respectively. We have:

$$n_A + n_B \leq N \tag{13}$$

$$n_B + n_C \leq N \tag{14}$$

Therefore, from the above two equations, $n_A \leq n_C$ or $n_C \leq n_A$. Also, WBAN 'C' can get the number of slots, i.e., $n_C \leq 2N - (n_A + 2 \times n_B)$. If the number of interfering WBANs for WBAN 'B' (but not WBAN 'A') increases to 'K', then the number of slots, say 't', which is available for use by each WBAN 'C' satisfies t $\leq \frac{2N-(n_A+2\times n_B)}{K}$.

The exchange of slot information among WBANs is

Algorithm: Exchange of TDMA Schedule

Inputs: An array of the SIR values, SIR threshold(δ_T)
Output: Exchange schedule if it finds necessary; otherwise, no exchange
Procedure:
$done \leftarrow false$
Each WBAN Coordinator measures its SIR
if $(SIR < \delta_T)$ **then**
    Calculate the *victim* probability Pr
    if (Pr is high) **then**
        while (*not done*) **do**
            Wait for random time
            Broadcast the TDMA schedule
            $W_t \leftarrow WaitforAcknowledgement$
            if ($W_t > T_t(Time\ out)$) **then**
                Repeat the loop three times
            else
                $done \leftarrow true$
            end if
        end while
    else
        No Exchange
    end if
    if (*done*) **then**
        Exchange of the schedule has occurred
    end if
end if

Fig. 4: Algorithm for Exchange of TDMA Schedule

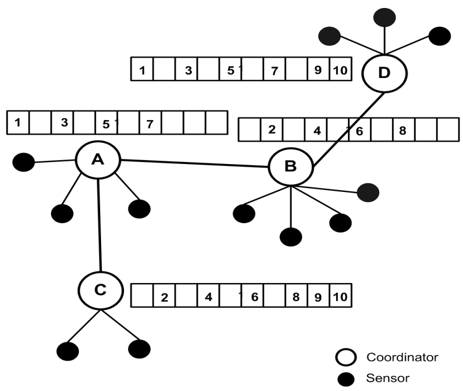


Fig. 5: Reuse of slots

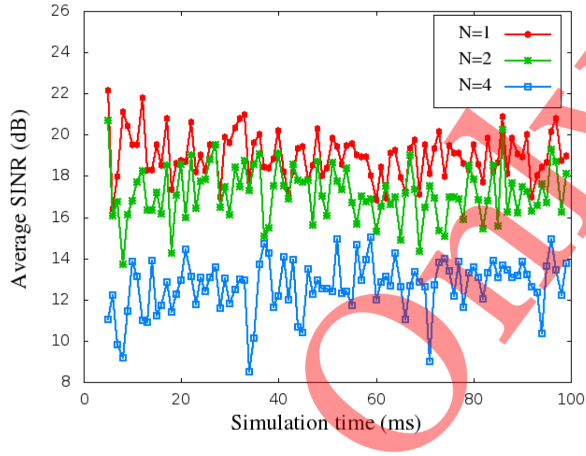
carried out through the following steps:

1) The coordinator of each WBAN knows the number of required slots during the control phase prior to the start of the data phase in the superframe.
2) The exchange of these slot information among the WBANs takes place during the control phase of the frame, only when it is required.
3) One of the WBANs broadcasts the computed common slot information to the interfering neighbors. Upon receiving the slot information, the neighbors send a confirmation message which consists of the number of slots and the slot number.
4) The two-hop neighbors have the information about the neighbors that are already committed to certain slots and they can use the other unused slots.

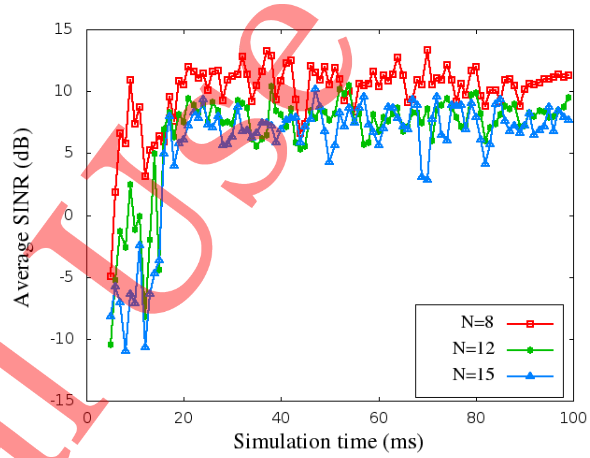
There exists different mechanisms to assign time slots and bandwidth in a distributed manner to different mobile nodes, some of which are mentioned below. A mechanism to calculate the bandwidth of a link in a TDMA-based wireless mobile networks is proposed in [17]. An admission control mechanism with bandwidth as the QoS parameter is proposed [18] for time-slotted multi-hop mobile networks. Similarly, an interference-aware bandwidth allocation algorithm for QoS routing in TDMA-based wireless ad hoc networks is proposed in [19]. Also, a position-based QoS routing scheme for UWB mobile ad hoc networks is proposed in [20]. However, all the above discussed mechanisms can only be applied in source-to-destination networks. In such networks, the decision of one node depends on other's. For example, the bandwidth requirement at all the intermediate nodes should be satisfied in order to accomplish the communication between the source and the destination nodes.

The sufficient conditions for flow admission control in wireless ad-hoc networks are given in [21]. However, those conditions can only be applied to IEEE 802.11 MAC and TDMA MAC in mobile ad hoc networks. In these MAC protocols, the transmission schedule consists of transmitting and receiving slots. However, the coordinator of TDMA-based WBANs has the schedule of only the receiving slots.

Let us consider a network of interfering WBANs as a graph G(V,E), where each WBAN is a subgraph and each vertex, 'V' of the graph represents a node in the network, E represents the set of edges in the graph. An edge of the graph represents a link between two nodes. F is a set of flow vectors, i.e., F = $\{F^1, F^2, ..., F^k\}$, where F^k is the flow vector of the k^{th} subgraph in the interference graph. Let the i^{th} flow element of the k^{th} subgraph in the graph be F_i^k, where i = $\{1, 2, ... , \ell \}$,



(a)



(b)

Fig. 6: Average SINR versus simulation time. The attenuation factor η = 2.0 and N represents the number of co-existing WBANs

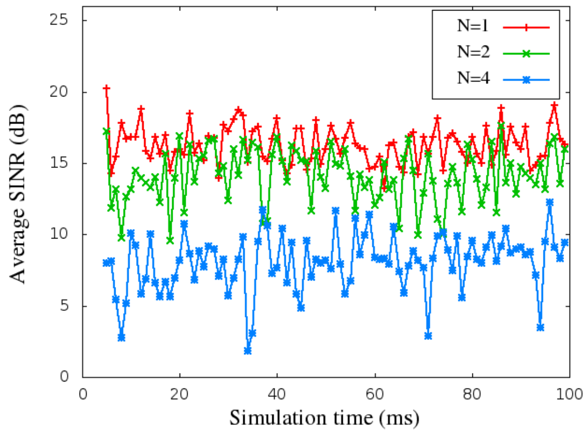
ℓ is the number of links present in the subgraph. The flow requirement of the i^{th} link in the k^{th} subgraph is r_i bps. Therefore, the total flow requirement, F^k, at the coordinator is $\sum_{i=1}^{\ell} r_i$. The following condition derived for the interference graph decides whether the flow vector, F, is feasible for a given schedule. Given the bandwidth (W) of the channel, the following condition controls the admission of new WBANs which want to join the network interference graph:

$$\{F^k \ \epsilon\ F \mid F^k \leq (W - \sum_{j\ \epsilon\ Nei(k)\ \&\&\ (j!=k)} F^j)\}$$

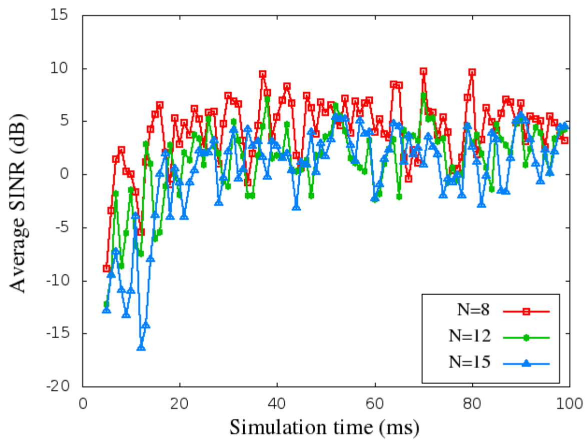
where, Nei(k) is the list of neighbours of the k^{th} WBAN.

VI. Performance Evaluation

In this section, we report the results of simulation experiments conducted using NS-3 to investigate the performance of the proposed scheme for mitigating network

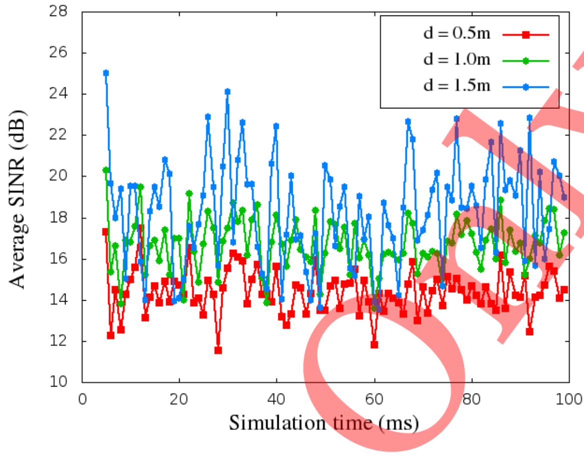


(a)

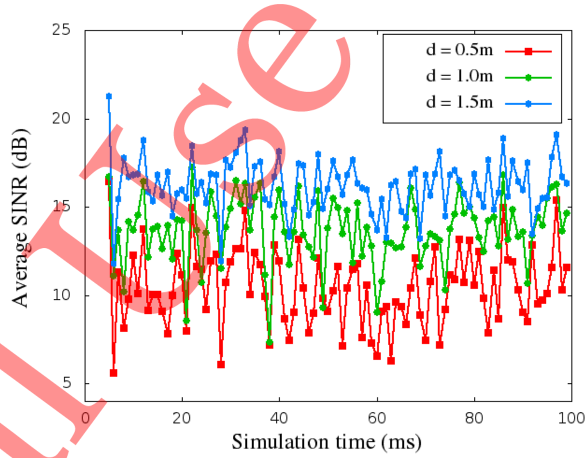


(b)

Fig. 7: Average SINR versus simulation time. The attenuation factor η = 3.0, and N represents the number of co- existing WBANs.



(a) The attenuation factor η = 2.0



(b) The attenuation factor η = 3.0

Fig. 8: SINR versus simulation time

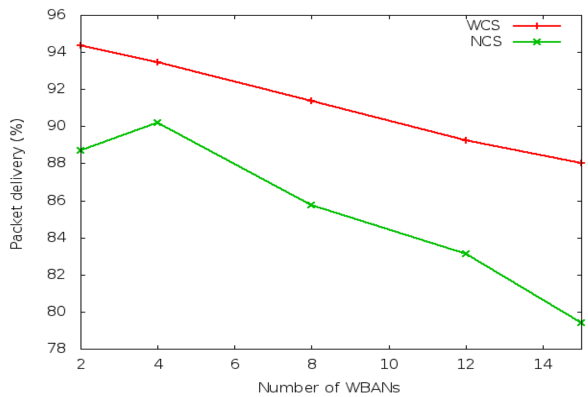


Fig. 9: Number of WBANs versus packet delivery (%)

interference arising due to the co-existence of different WBANs.

A. *Simulation Settings*

A simulation area of 10 m $\times$ 10 m is considered. The Random-Waypoint (RWP) mobility model is used in the simulation experiments to move the WBANs randomly within the simulation area. The nodes of a WBAN move to a random position with a constant speed by uniformly selecting the radius and angle from the position of the coordinator. We executed the simulations for 100 seconds with different set of parameters such as the number of WBANs and their speed.

B. *Performance metrics*

We used the following three perfomance metrics to evaluate the performance of the proposed solution.

- *Percentage of Packet Delivery :* It is defined as the percentage of packets received by the coordinators from their respective sensor nodes.
- *Average Latency per Node :* It is defined as the total average time a sensor node on a WBAN waits to start its transmission.

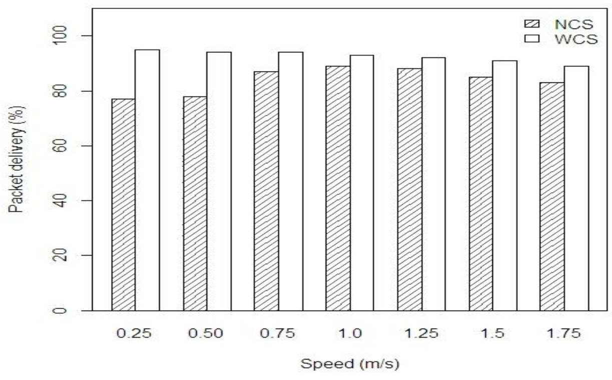


Fig. 10: Speed of WBANs versus packet delivery (%)

- *Percentage of Calls Admitted:* The percentage of admitted flows in the network from the total number of flows present in the network interference graph or contention graph of interfering WBANs. It is calculated as below:

$$\frac{\Upsilon_a}{\Upsilon_f - \Upsilon_i} \times 100$$

where, Υ_a, Υ_f and Υ_i, are the number of flows admitted, total flows, and number of independent flows, respectively. The independent flows are generated by the WBANs that are not the neighbors of any other WBANs in the network. These flows do not appear in the contention graph in the network.

C. Results and Disscusion

In order to study the interference effects between WBANs, the mobility for these WBANs is set in such a manner that they move within the confined space and meet one another at some point. This simulation setting was made to observe the change of SINR value of the coordinator. In other words, we studied the degradation of signal of a WBAN due to interference with other WBANs. The results given in Figs. 6-8 show that the average SINR value of WBANs changes as long as they are within the range of one another. For N=2, and 4, a WBAN interferes with another WBAN located at a distance of 0.3 meter, and three WBANs standing colinearly 0.3 meter apart from each other, respectively. For N=8, 12, and 15, WBANs stand on a straight line such that all are accommodated within the 2 meters range. Fig. 6 shows that the average of the SINR values taken over each second of the simulation time at one of the coordinators decreases while the number of coexisting WBANs increases. The value of attenuation factor in this case is 2.0. The same fact was also observed with different values of attenuation factor (η = 3.0), as shown in Fig. 7. However, the effect of interference becomes increasingly prominence as the SINR decreases aproximately by 2 dB in all cases. In Fig. 8, the average SINR value increases when the distance between the coordinators increases. Also, we studied the exchange of common schedule (i.e., when the number of times the SINR value reduces below the threshold) is required in order to improve the packet delivery ratio in the WBANs. The SIR threshold value at the physical layer device and the attenuation factor (η) are considered to be 10 dBm, and 3.0, respectively. An on-off application is used by the nodes to generate packets for the transmission to the coordinator. It was observed that the increase in the number of WBANs results in the decrease in the percentage of packets delivered. This is shown in Fig. 9. In another experiment, we varied the speed of WBANs and observed the decrease in the percentage of packets delivered. Our proposed scheme shows better performance when the relative speed of the mobile WBANs is smaller. In other words, it can be inferred that the WBANs staying for longer duration in the range of one another could benefit from the exchange overhead. In high mobility environments, the WBANs may come within the range of one another for very short time and during the exchange of common schedule they may go out of range. Thus, the exchange of schedules schedules by WBANs in such scenarios is of limited help. The speed of WBANs versus the percentage of packets delivered is shown in Fig. 10. The latency per node increases when the number of WBANs increases in the network, as shown in Fig. 11. For all the above cases, we compared the proposed scheme, referred to as *With Common Schedule* (*WCS*), with a simple approach, referred to as *No Common Schedule* (*NCS*), where WBANs move inside the simulation area and they do not use common schedule when interference between them occurs.

In Fig. 12, we show the percentage of flows admitted by the proposed scheme, while varying the average flows in the network. In this experiment, the positions of WBANs were uniformly distributed within the simulation area. The WBANs are considered to be contending for the channel when they are within the 2 meter radius of one another. The flow requirement for each WBAN is generated using normal distribution with mean (μ), and standard deviation (SD). We considered the SD value as 10 kbps and varied the mean of the flow vector from 20–150 kbps in the experiments. We collected the results for different network sizes in the range 10–40. For each network size, we executed the simulations 100 times by varying the flow with different mean values. We observed

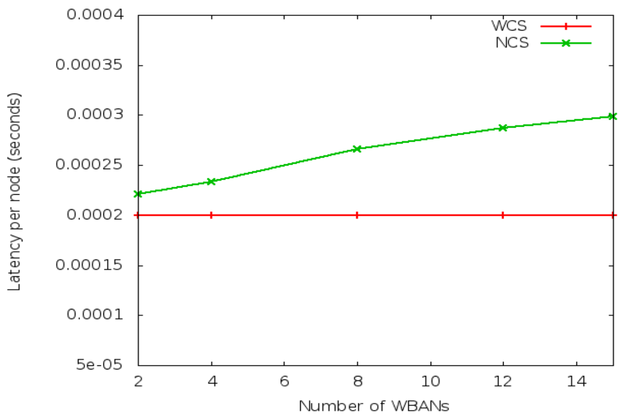


Fig. 11: Number of WBANs versus latency per node

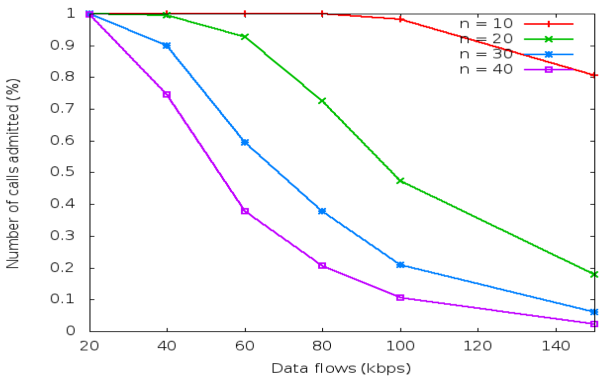


Fig. 12: Data flows (kbps) versus number of calls admitted (%)

that the percentage of flows allowed decreases when the flow rate increases. For small network sizes, by varying the flow rate, we observed that the admitted flow rate in the network slowly decreases.

VII. Conclusion

In our work, we investigated the effect of network interference between multiple TDMA-based WBANs, and then proposed a scheme for mitigating the problem using the concept of sharing common schedule. We observed that the proposed scheme reduces its interference level to a much minimal value after exchanging the common schedule among the different WBANs that are in the proximity of one another. The existence of neighbours in the network is sniffed through the change of SIR value at the coordinators.

In the future, we intend to look into some light-weight adaptive learning mechanisms which can monitor the continuous change of SIR values, and provide better predictions for the existence of neighbors. We would like to further investigate improved flow conditions. Further, we plan to investigate our proposed solution on testbeds and real deployment in hospital environments.

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