A Study of Resource Assignment in ZigBee Personal Area Networks

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1 Introduction

Personal healthcare is a promising market of a Personal Area Network (PAN). The PAN consists of a data collector and multiple wearable sensors which must send data to the collector according to the frequency specified by each PAN. The data collector may be any hand-held or portable device, e.g., a mobile phone or a PDA (personal digital assistant). An individual user uses a PAN in order to detect, track, or manage his/her health. ZigBee [2] is considered as a wireless medium between the data collector and the sensors because it is mainly developed for PANs and has an advantage of very low energy consumption in comparison with other short-range wireless communication standards.

Multiple PANs for aforementioned purposes are likely to coexist in a same area, especially a place where a large number of users exist. Because multiple PANs must share resources (e.g., wireless channels, transmitting time) in this scenario, a problem of packet collisions among such PANs is unavoidable. As a result, the personal healthcare system using PAN cannot be provided as a service for the users because the data collector cannot collect sensing data from each sensor correctly. Therefore, we have proposed an adaptive scheme to assign resources for coexisting PANs [1].

This paper studies resource assignment in ZigBee personal area networks by comparing our adaptive scheme and standard ZigBee. The adaptive scheme distinguishes a PAN and a node when assigning resources such as wireless channel and transmitting time. Resources are dynamically assigned according to the current number of PANs that exist in the same area. In particular, the proposed scheme automatically re-assigns resources when any PANs come into or leave from the coexisting area. As one of salient features, our scheme assigns transmitting time to meet a requirement on reporting interval determined by an application. Thus applications that are sensitive to delay can collect sensing data correctly and in time. The simulation results show that our scheme achieves higher packet delivery rate than the standard ZigBee, although multiple PANs coexist in the same area.

2 Overview of Resource Assignment Algorithm

We brief the resource assignment algorithm [1] in this section. The proposed algorithm can be divided into two main steps: (i) resource assignment between PANs, and (ii) resource assignment within a PAN.

A ZigBee Coordinator (ZC) starts its PAN by randomly selecting a channel from unoccupied channels, and determines the duration of a shared *time frame* (T) arbitrary. All the PANs that use the same channel share this time frame. Each ZC maintains its *active period* ($\alpha\ T$, where $0 < \alpha \leq 1$) and *starting time* (τ) in order to know a period of time that is assigned to its PAN and the beginning of that active period. The starting time is updated every time frame by adding T seconds. After knowing the active period, a ZC assigns time equally to each ZigBee End Device (ZED) in its PAN.

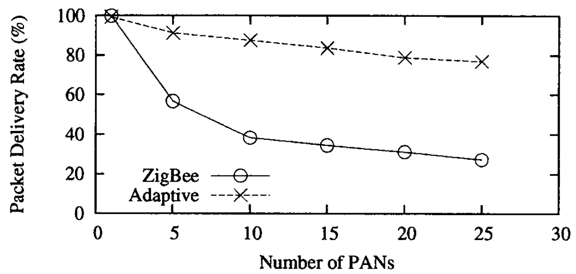
Not only its own α and τ, but each ZC also maintains α and τ of the following PANs in a management table: (i) a PAN whose active period follows its active period immediately; (ii) a PAN whose active period starts from the beginning of the shared time frame if and only if its active period follows that PAN immediately. Every ZC periodically broadcasts α, τ, and other information at the beginning of its active period through a beacon message. When any PAN in the management table lost due to absence of beacon messages, the PAN who manages that table will take absent PAN's time and merge with its time. As an addition rule, a ZC will extend its active period if possible according to received beacon messages.

If all channels are occupied, it will request time from the PAN using the chosen channel. When a PAN receives a request, it gives the latter half of its active period to the requester if possible.

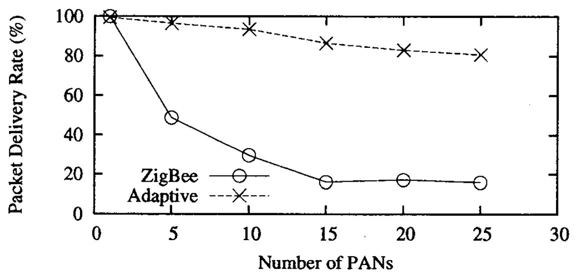
According to the above procedures, there is a chance that two or more groups of multiple PANs which have already allocated their time frame encounter each others somewhere. In this case, active periods are reallocated by using the shortest time frame as a shared time frame of all groups in order to avoid conflict requests and overlapped active periods. In particular, all ZCs using longer time frame send requests for new active periods, while ZCs using the shortest time frame do nothing. The procedures for determining and allocating active period are the same as above. If there are multiple groups whose time frames are the shortest, any further metrics (e.g., a time frame ID) can be used to determine the PAN whose time frame will be used as a shared time frame because all PANs have the same priority to serve this role.

3 Performance Evaluation

We used ns–2.30 simulator in our experiments. PANs are deployed in a square region of 30 m by 30 m. The number of PANs is varied from 1 to 25. Each ZC is attached with three ZEDs which report sensing data to their ZC every 800 ms. Each PAN moves by following the random waypoint model in which maximum speed is 0.8 m/s. Note that all nodes (ZC and ZEDs) which belong to the same PAN always move together in order to construct a star topology of PAN. Communication range of each node is set to 15 meters so as to realize coexisting scenarios easily. Available channel is set to only one channel because nodes using our adaptive scheme can send data correctly if the number of available channels is more than the number of PANs in the network. The simu-



(a) Moving scenario.



(b) Standstill scenario.

Figure 1 Packet delivery rate when varying the number of PANs that use the same channel.

lations last for 2,100 seconds for each experiment. We also evaluate the scenario where all nodes are at a standstill and stay within communication range of each others. This experiment imitates a scenario where people stay together in a small area such as train, conference room, etc.

Packet delivery rate of the moving scenario is shown in Figure 1(a). Both the standard ZigBee and our adaptive scheme work well when only one PAN exist because any resource assignment is not required. As one would expect, the percentage of dropped packets increases when the number of PANs increases due to limited wireless resources. Because the ZEDs using the standard ZigBee specification send packets without considering neighboring PANs or nodes, the probability of collision and congestion are very high. As a result, the packet delivery rate of the standard ZigBee drops below 60% although only five PANs exist in the field. This means five persons equipped with PANs cannot exist in the same area. When the number of PANs increases to 25, the packet delivery rate drops below 30% which is intuitively an unacceptable value for any applications. In contrast, our adaptive scheme tries to assign available resources (time) to every coexisting PANs and ZEDs. Therefore, the packet delivery rate drops slower than those of the standard operation of the ZigBee, and are still higher than those of the ZigBee 30%–50%.

The PANs in Figure 1(b) is deployed in a nearby area where any node is within the communication range of all other nodes. It is not surprising that the situation is worse for the ZigBee-operated nodes in comparison with the moving scenario because all PANs always stay in the same area for all the times. In contrast, our adaptive scheme works better than the moving scenario because once the resource assignment has finished, every node can send packets without any collision if the resources are much enough. In the moving scenario, the resources need to be re-assign when the PANs join or leave the group.

The trend of end-to-end delay is the same for both the moving and standstill scenarios. The ZEDs using our approach must wait and send the packets within the assigned time. As a result, the delays of our adaptive approach are much longer than those of the standard ZigBee. However, even if how fast the standard ZigBee can deliver the packets, it is useless if more than half of the generated packets are dropped.

The delays of our approach depend on the length of time frame, i.e., the delays are approximately half of the selected time frame if the packets are generated randomly. In particular, if a packet is generated within the assigned time, the packet can be sent immediately with a very short delay. On the other hand, if a packet is generated immediately after the assigned time has finished, the packet will be buffered until the next assigned time. Since a period between two assigned times is approximately equal to the time frame, an average delay of all randomly generated packets is roughly equal to half of the time frame. Our simulation results also confirm this intuitive statement.

We conclude that our scheme still achieves high delivery rate when the number of PANs using the same channel increases to 25. Because there are 16 channels for 2.4 GHz ZigBee, our scheme can support at least 400 coexisting PANs. In contrast, the packet delivery rate of standard ZigBee starts to worse at five PANs, which means standard ZigBee cannot support more than 80 PAN when using all available channels.

4 Conclusion and Future Works

We have studied the performance of the proposed adaptive scheme through simulated networks by comparing to the normal operation of ZigBee specification. The results showed that our proposal is a promising solution to deal with coexisting PANs, and the ZigBee standard lacks a function against this kind of problem. We also developed a prototype of cellular phone equipped with ZigBee module for the personal healthcare applications. The proposed scheme is also implemented in the prototype and seems to work properly. One of the future works is to evaluate the performance of the proposed scheme through this prototype.

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