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Performance improvement in ZigBee-based home networks with coexisting WLANs

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ABSTRACT

In recent years, a large diversity of network-enabled devices have been widely prevalent in home environment. With the prevalence of such devices, wireless home networks enable monitoring and control applications for home user comfort and efficient home management. In the home network, alarm signals must be delivered in real-time to the residents or to the emergency services and some home control applications require the response time to be on the order of a few hundred milliseconds for optimal user experience. Most recently, ZigBee has emerged as one of the most promising technologies for wireless home networking because it is targeted at applications that require a low data rate and long battery life, which are also the features of home network applications. However, its usage in close proximity to Wireless Local Area Networks (WLANs) introduces coexistence problems, resulting in failing to fulfil the response time required by the home control applications. To overcome this problem, we propose to control the WLAN traffic when there exist ongoing ZigBee transmissions and the maximum tolerable delay is not met due to the WLAN interference. We aim to guarantee that the delay experienced by ZigBee sensors (especially, for alarm signals) does not exceed the maximum tolerable delay, while maintaining as high throughput as possible in the WLANs. The simulation results demonstrate that our proposed algorithm can enhance the delay performance of ZigBee networks by mitigating the effect of WLAN interference and improve the throughput in the WLANs.

1. Introduction

In recent years, the home environment has seen a rapid introduction of a large diversity of network-enabled devices/machines/terminals, including smartphones, laptops, personal computers, TVs, lights, and electronic appliances. With the dramatic penetration of such network-enabled machines, Machine-to-Machine (M2M) communications will become a dominant communication paradigm in home networks, providing exciting opportunities to increase the connectivity of devices within the home for the purpose of home automation. In the home networking system, intelligent home appliances can autonomously maximize energy savings and consumers can control their home appliances locally or even remotely [1–3].

On the other hand, ZigBee has become a wireless networking technology employed by smart home solutions since it is targeted at applications that require a low data rate and long battery life. Indeed, home network applications generally feature low data rate, low mobility, and low power consumption [1–3]. The representative use case of home network

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applications is home automation and control where customers can monitor and control the home (temperature, humidity, activation of remote video surveillance, status of the doors, etc.) through local or remote access through the Internet [4]. In addition, the ZigBee Alliance has recently defined the home automation public application profile that specifies device attributes and commands for applications in a residential environment [5].

In the home networks, humidity/temperature sensing is typically not critical, whereas alarm signals for detecting possible risk situations (e.g. tele-assistance, life critical medical data, and gas-leak detection) must be delivered to the emergency services in real-time and require a high degree of reliability. In addition, some home control applications require the response time to be on the order of a few hundred milliseconds for optimal user experience (e.g., use a remote control to switch a light on) [2,4,6]. However, as ZigBee networks within homes has become widespread, their usage in close proximity to WLAN using the IEEE 802.11 standard introduces coexistence problems, resulting in failing to fulfil the response time required by the home control applications. In particular, most ZigBee channels are overlapped with those of WLANs, resulting in significant service degradations in interference scenarios since the transmission power of ZigBee is far weaker than that of WiFi [1,7,8].

Yu et al. proposed a distributed rate and admission control scheme to improve the Quality of Service (QoS) of multimedia sharing in home M2M networks by integrating a game theory framework to model the contention of radio resource among multiple service flows [9]. The scheme predicts the QoS performance and adaptively regulates the source rate to accommodate more media sessions, assuming a p-persistent CSMA/CA system. But, they do not deal with the interference problem in ZigBee-based home networks coexisting with WLANs.

In recent years, there have been various studies on interference mitigation to improve ZigBee in coexistence environments. Won et al. proposed an adaptive channel allocation scheme for ZigBee and WiFi coexistence which enables ZigBee to utilize multiple channels in a Personal Area Network (PAN); each PAN is assumed to use only one channel [10]. Xie and Howitt introduced a load balancing scheme for WLAN/ZigBee interference environments to minimize the overall system resource utilization in both WLANs and ZigBee WPANs [11]. However, they did not examine how the interference from the WLANs will affect the performance of the WPANs. Liang et al. quantified the interference patterns between IEEE 802.11 and 802.15.4 networks at bit-level granularity and introduced a solution that enables IEEE 802.15.4 nodes to coexist with WiFi networks [8]. Although the solution is able to reduce the IEEE 802.15.4 packet loss rate due to IEEE 802.11 interference at the bit-level, it cannot guarantee the reliable delivery of smart grid/home control messages requiring with high QoS satisfactions, while the 802.15.4 network is suffering from the interference. Yi et al. evaluated ZigBee performance under WLAN interference for smart grid applications and proposed an interference mitigation scheme where once interference is detected, the coordinator selects the channel with the low noise levels and then requests all nodes in the PAN to migrate to this channel [7]. Based on the simulation results, they suggested a "safe" distance and safe offset frequency to guide ZigBee deployment in the presence of IEEE 802.11 interference. However, it is not easy to maintain the safe distance/offset frequency due to the inherent movements of WLAN users. Further, in the scheme, there still remains a delay in detecting the interference. Most recently, Zhang et al. proposed a mechanism called Cooperative Carrier Signaling (CCS), that exploits the inherent cooperation among ZigBee nodes to harmonize their coexistence with WLANs. CCS employs a separate ZigBee node to emit a carrier signal concurrently with the desired ZigBee's data transmission, thereby enhancing the ZigBee's visibility to WLAN [12].

On the other hand, we note that the popular applications used in the WLANs at home are known to be file transfer such as FTP and Peer-to-Peer (P2P), and audio/video streaming service [13]. It is also noted that the 802.11 Access Points (APs) at home are typically connected toward the Internet through the network operator's gateway. The network management and configuration of APs has become one of the main concerns of network operators. Based on these notions, the data traffic to/from the home APs can be controlled by the network operator in order to deliver the alert messages in real time or to meet the response time of the home control messages in the ZigBee-based home network. Specifically, we propose an algorithm that mitigates interference from IEEE 802.11 traffic by controlling the traffic in the WLANs at home dynamically with the aim to guarantee that the delay experienced by ZigBee sensors (typically, for alarm signals in emergent situations) does not exceed the maximum tolerable delay.

We analyze the delay from a ZigBee sensor to the coordinator and the throughput performance in the WLAN. Then, based on the analysis, we develop an algorithm that controls the load in the WLANs to mitigate the interference in the ZigBee network and to maximize the throughput in the WLAN when the interference to the ZigBee network is low. We demonstrate via simulations that our proposed algorithm can enhance the delay performance of ZigBee network by mitigating the effect of WLAN interference and improve the throughput performance in the WLAN under conditions of low interference from the WLANs.

The rest of this paper is organized as follows. Section 2 presents the analytical models of WLAN throughput and delay in the ZigBee network and the details of the proposed interference mitigation algorithm. In Section 3, we conduct simulation experiments to demonstrate the performance improvements from the proposed algorithm. Finally, Section 4 concludes the paper.

2. Interference mitigation scheme for ZigBee networks with coexisting WLANs

In this section, we describe our proposed interference mitigation algorithm that regulates the load in the WLANs to meet the ZigBee delay requirement, while improving the WLAN throughput. We aim to meet the delay requirement of signals to