A Comparison between Collaborative and Non-Collaborative Coexistence Mechanisms for Interference Mitigation in ISM Bands

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Abstract

Wireless systems operating in the ISM frequency bands and sharing the same environment are likely to interfere with each other. We address the problem of coexistence between IEEE 802.11 and IEEE 802.15 devices, and we present a mechanism that mitigates the interference between these devices when IEEE 802.15 supports voice traffic. The proposed scheme can work when 802.11 and 802.15 devices operate in non-collaborative mode, i.e., independently of one another. The performance of the proposed algorithm is compared to the results obtained through the so-called MEHTA scheme, which is a collaborative mechanism recently presented to the IEEE 802.15 Working Group. Simulation results show that the proposed algorithm gives good performance relatively to the MEHTA scheme when co-located interfering devices only are considered, while it outperforms the MEHTA scheme when non co-located interfering devices are present.

1. Introduction

In this paper, we deal with the problem of mutual interference between IEEE 802.11 WLANs (Wireless Local Area Networks) [1, 2] and short-range radio systems based on the Bluetooth technology [3], or equivalently, IEEE 802.15 WPANs (Wireless Personal Area Networks) [4]. These systems will operate in the ISM (Industrial, Medical and Scientific) frequency bands, i.e., the unlicensed spectrum at 2.4 GHz. IEEE 802.15 uses a FHSS (Frequency Hopping Spread Spectrum) scheme, while IEEE 802.11 can either use a FHSS or a DSSS (Direct Sequence Spread Spectrum) technique. Interference between 802.11 and 802.15 devices occurs whenever the interference energy is sufficient to cause a decrease of the signal to interference ratio at the receiver and the transmissions of the two systems overlap both in frequency and in time.

According to the IEEE 802.15 Working Group, *coexistence* of 802.11 and 802.15 occurs when the two systems can operate in a shared environment without significantly impacting the performance of each other [5]. In order to mitigate interference between the two wireless systems, the IEEE 802.15 Working Group has created the Task Group 2 (TG2), which is devoted to the development of *coexistence mechanisms* [4].

Two classes of coexistence mechanisms have been defined: collaborative and non-collaborative techniques [4]. With collaborative techniques it is possible for the WPAN and the WLAN to exchange information to reduce the mutual interference; collaborative techniques can be implemented when interfering devices are co-located in the same terminal. With non-collaborative techniques there is no way to exchange information between the two network systems and they operate independently.

In this paper, we present a coexistence mechanism based on a simple traffic shaping technique. The proposed mechanism is to be performed at the WLAN stations in presence of a 802.15 voice link. It does not require a centralized traffic scheduler and can be implemented in non-collaborative mode, thus allowing for interference mitigation between co-located and non co-located 802.11 and 802.15 devices. Performance, as well as advantages and disadvantages, of the presented algorithm are compared with those of the so-called MEHTA scheme [6], which is a collaborative algorithm proposed within the IEEE 802.15 Working Group.

The remainder of the paper is organized as follows. In Section 2, we briefly introduce the 802.11 and 802.15 technology. Section 3 presents the MEHTA scheme and the proposed non-collaborative coexistence mechanism; Section 4 describes the simulation scenario. Section 5 shows performance results; finally, Section 6 concludes the paper.

2. System Scenario

We consider a IEEE 802.11 WLAN operating at 11 Mb/s and using a DSSS (Direct Sequence Spread Spectrum) scheme [1]; the WLAN bandwidth is taken equal to 17 MHz [7]. The fundamental building block of the network is the so-called Basic Service Set (BSS), which is composed of several wireless stations that are under the control of the same MAC function. Wireless stations can directly communicate with each other forming an ad-hoc network, or through a centralized access point, which also provides a connection to the wired network [1]. We assume that the WLAN supports asynchronous data transport and uses as MAC scheme a DCF (Distributed Coordination Function), which is based on the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol [2].

IEEE 802.15 WPANs are intended to provide interconnection of devices in the user's vicinity. The basic architectural unit is the piconet, composed of a *master* device and seven active *slave* devices at most, which are allowed to communicate with the master only [3]. IEEE 802.15 can provide a bit-rate equal to 1 Mb/s. A FHSS scheme is used at the physical level; hopping frequencies range over 79 frequency channels in the ISM band, each of the channels being 1 MHz wide. The nominal hop dwell time is equal to 625 μs. A TDD technique is used to transmit and receive data in a piconet: each packet transmitted in a slot corresponds to the minimum dwell time; slots are centrally allocated by the master and alternately used for master and slave transmissions.

Interference between 802.11 and 802.15 arises whenever the interfering power from a 802.15 (802.11) transmitter causes a significant decrease of the carrier to interference power margin at the 802.11 (802.15) receiver [8, 9, 10]. For a set of WLAN and WPAN nodes interfering with each other, a collision occurs whenever their transmissions overlap both in frequency and in time [11].

3. Coexistence Mechanisms

We first describe the so-called MEHTA scheme, that has been recently presented to the IEEE 802.15 Working Group. Then, we introduce a novel coexistence algorithm based on a simple traffic shaping technique, and we compare its performance with the one obtained when the MEHTA scheme is applied.

The MEHTA scheme. An example of collaborative coexistence mechanism is the scheduling algorithm called MEHTA [6], which has been proposed to mitigate the interference between a 802.15 device and a 802.11 device that are co-located in the same terminal. MEHTA involves the use of a centralized controller, that monitors the 802.15 and the 802.11 traffic and allows exchange of information between the two radio systems. The controller works at the MAC layer and allows precise timing of packet traffic, thus avoiding interference between the two devices. 802.15 voice traffic has priority over WLAN packets, otherwise WLAN traffic is transmitted first. When there is voice traffic pending, WLAN packets are queued.

The proposed mechanism. It is a non-collaborative algorithm that is performed at the 802.11 stations to mitigate the interference due to 802.15 devices supporting voice traffic.

In 802.15 WPANs, in the case of voice traffic slots are allocated according to a deterministic pattern. For instance, for each phone call using a HV3-type link [3], a single-slot packet is transmitted periodically on both the uplink and the downlink direction every six time slots. Thus, to avoid overlap in time between 802.11 and 802.15 transmissions, a WLAN station shall start transmitting when the 802.15 channel is idle and adjust the length of the WLAN packet so that it fits between two successive 802.15 transmissions. We consider that the WLAN stations may become aware of which time slots are busy over the 802.15 channel by listening to the radio channel. This information is directly used by the WLAN stations to reduce the probability of collision with the WPAN devices, without requiring any centralized controller.

Whenever a WLAN station is ready to transmit, it checks on the status of the interfering 802.15 channel. If the channel is idle and is expected to remain so for the next $i - 1$ slots, the WLAN station transmits a data packet with payload size equal to the minimum between $(i \cdot 500)$ bytes and 1500 bytes. Conversely, if the 802.15 channel is busy, the WLAN station sends a packet with a 500 bytes payload. Notice that the minimum payload has been set to 500 bytes to make the corresponding WLAN packet transmission time comparable to the duration of a single-slot 802.15 packet.

Notice that this scheme does not require a central traffic scheduler, and it can be implemented in non-collaborative mode thus allowing for interference mitigation between co-located and non co-located 802.11 and 802.15 devices.

4. Simulation Scenario

We consider a IEEE 802.11 ad-hoc network; all the stations operate as a self-contained BSS and are able to directly communicate with each other. The arrival of frames from a station's higher layer protocol to the MAC sublayer is modeled with exponential inter-arrival times and a truncated geometric distribution for the frame lengths [12]. The mean value of the truncated geometric distribution is set to 1500 bytes, while the maximum frame length is set to the maximum length of the MAC Service Data Unit (MSDU) established by the IEEE 802.11 standard (i.e., 2296 bytes).

The parameter of the exponential distribution is a varying parameter in the simulations.

Table 1. Parameters used in the simulation of the IEEE 802.11 system.

Parameter	Assigned Value
Long_Retry_Limit	10
Physical Header	144 bits
MAC Header	272 bits
Slot_Time	20 μs
SIFS	10 μs
DIFS	50 μs

In order to reduce the complexity of the simulation model, the following further assumptions have been introduced: (1) possible values for the WLAN packet length have been limited to 500, 1000 and 1500 bytes; (2) the RTS/CTS mechanism is assumed to be always active; (3) no interference is considered from nearby BSSs using the same DSSS spreading sequence; (4) propagation delay is neglected, which is a reasonable assumption due to the small distance between stations; (5) transmission errors due to the radio channel are neglected.

A IEEE 802.11 transmission is considered to be successful if no collision occurs on the RTS frame and both the data packet and the corresponding acknowledgment sent by the receiver are correctly received. If a packet is not correctly received, retransmission will take place according to the backoff procedure defined by the IEEE 802.11 standard. The number of retransmissions before the packet is discarded from the station buffer is limited and set to the Long_Retry_Limit. The values of the IEEE 802.11 parameters used in the simulation model are listed in Tab. 1.

For the IEEE 802.15 system, assumptions (4) and (5), introduced above for the 802.11 simulation model, still hold. We assume that voice traffic is transmitted by using a HV3-type link, i.e., for each active phone call a voice packet is transmitted in each direction every six time slots. Notice that in the HV3-link information in the payload is not FEC encoded [3].

The model adopted to evaluate the mutual interference between WLANs and WPANs is the one described in [11].

5. Results

We first consider a 802.11 device and a 802.15 device co-located in the same terminal, with the 802.15 device supporting voice traffic.

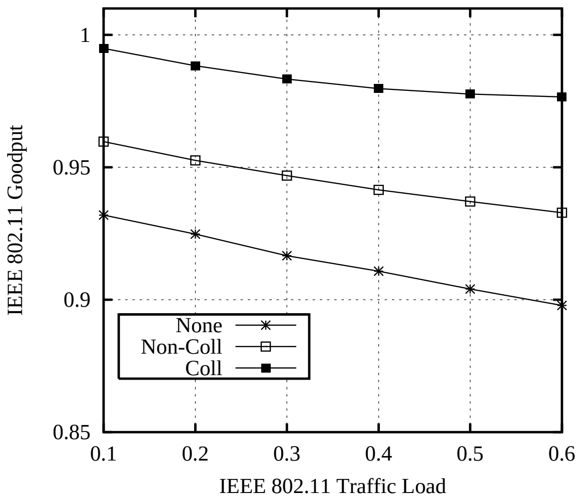

Figure 1. Goodput of a IEEE 802.11 device in presence of one co-located 802.15 interfering device supporting voice traffic. (None=no mechanism is applied; Non-Coll=the proposed scheme; Coll=MEHTA scheme.)

Fig. 1 presents the 802.11 goodput as a function of the 802.11 traffic load being the goodput defined as the fraction of transmitted information that is successfully transferred over the radio channel. Fig. 2 shows the goodput of the 802.15 device under the same operational conditions. As expected, in both the cases the collaborative MEHTA scheme gives the best performance while the lowest goodput is obtained when no mechanism is applied. Indeed, MEHTA always avoids transmissions overlap between 802.11 and 802.15 co-located devices by means of a precise timing the packet traffic. However, the excellent performance of MEHTA is achieved at the expense of a significant increase in the WLAN traffic delay. Fig. 3 shows the 802.11 average packet delay versus the WLAN traffic load, with the packet delay being the period from the time instant at which a packet is generated to the time instant at which the packet is successfully transmitted.

Figs. 4–6 refer to a scenario where, besides the co-located 802.11 and 802.15 devices, there are two more interfering WLAN stations. From Fig. 4, we can see that the proposed algorithm significantly outperforms the MEHTA scheme in terms of 802.11 goodput. While, as shown in Figs. 5 and 6, we obtain comparable performance for the 802.15 goodput and the WLAN average packet delay.

We conclude that MEHTA is able to give excellent performance in terms of goodput when interference is due to co-located devices only, at the expense of an additional delay in the WLAN packet transfer and of an increased system

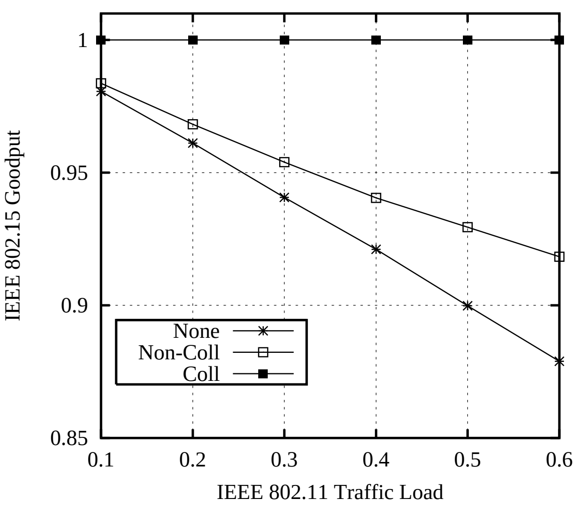

Figure 2. Goodput of a IEEE 802.15 device supporting voice traffic in presence of one co-located 802.11 interfering device. (None=no mechanism is applied; Non-Coll=the proposed scheme; Coll=MEHTA scheme.)

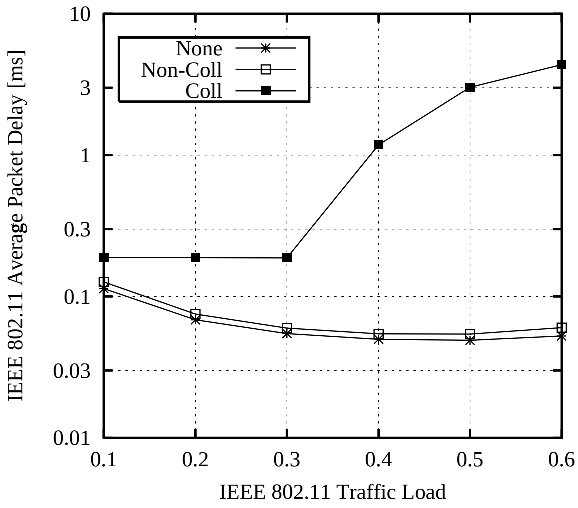

Figure 3. IEEE 802.11 average packet delay; the 802.11 device is co-located with a 802.15 device supporting voice traffic. (None=no mechanism is applied; Non-Coll=the proposed scheme; Coll=MEHTA scheme.)

complexity. When non co-located devices are present, the proposed coexistence mechanism is preferable to MEHTA since it gives very good performance and does not significantly increase the system complexity.

6. Conclusions

In this paper, we addressed the problem of coexistence between IEEE 802.11 WLANs and IEEE 802.15 WPANs. We proposed a non-collaborative mechanism that reduces the interference between the two network systems in the case where WPANs support voice traffic. The proposed scheme is compared with a collaborative solution, the so-called MEHTA, that has been proposed within the standardization process of IEEE 802.15 systems. The proposed non-collaborative mechanism does not require a centralized traffic scheduler and is able to mitigate the interference between co-located and non co-located 802.11 and 802.15 devices.

The presented results showed that when co-located 802.11 and 802.15 devices are considered, MEHTA gives a better goodput with respect to the proposed algorithm at the expense of a significant additional delay in the WLAN traffic transfer. When non co-located interfering devices are present, the proposed algorithm becomes preferable to the MEHTA scheme.

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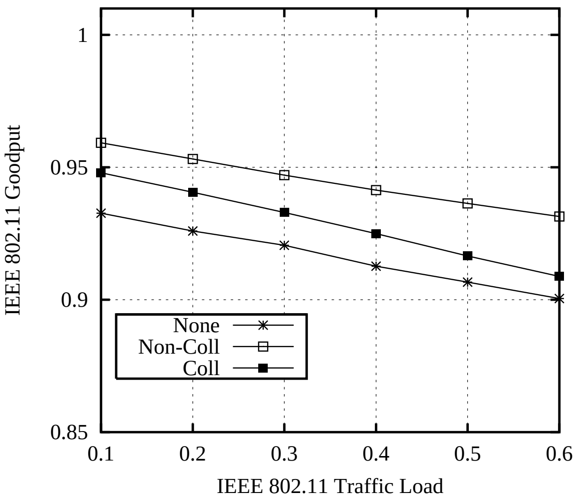

Figure 4. IEEE 802.11 goodput when more than one 802.11 device are considered; one 802.11 device is co-located with a 802.15 interfering device supporting voice traffic. (None=no mechanism is applied; Non-Coll=the proposed scheme; Coll=MEHTA scheme.)

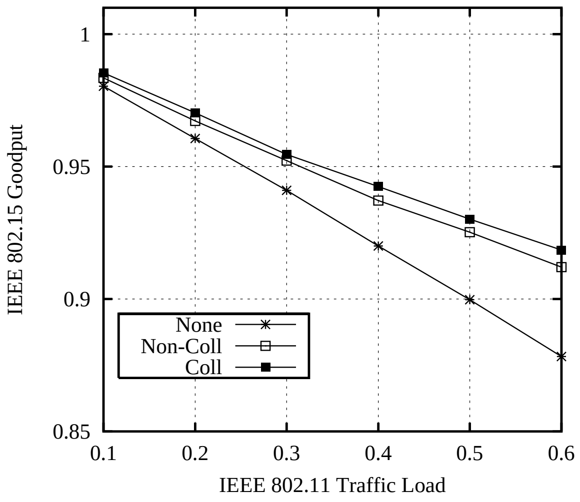

Figure 5. Goodput of a IEEE 802.15 device in presence of 802.11 devices; one of them is co-located with the 802.15 device. (None=no mechanism is applied; Non-Coll=the proposed scheme; Coll=MEHTA scheme.)

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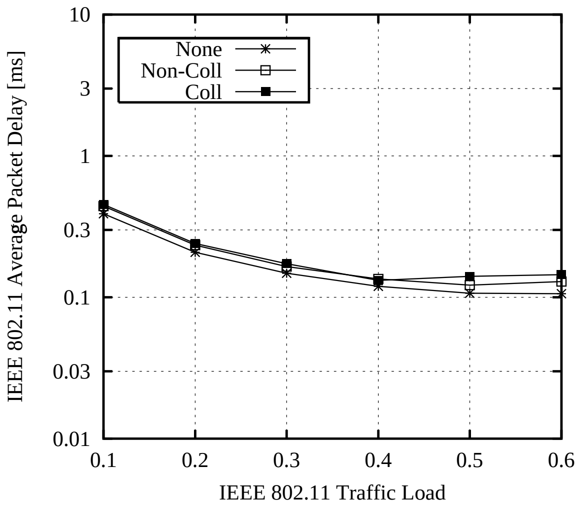

Figure 6. IEEE 802.11 average packet delay when more than one 802.11 device are considered. One of the 802.11 devices is co-located with a 802.15 device supporting voice traffic. (None=no mechanism is applied; Non-Coll=the proposed scheme; Coll=MEHTA scheme.)