Integration of WPAN with WLAN for Multimode Reconfigurable Device

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***Abstract* -- An innovative way of building a personal network (PN) is through an adaptive integration of personal area networks (PAN) with other infrastructure networks. IEEE 802.15.3 is a prominent PAN standard for high data rate air interface. IEEE 802.11 is a successful and popular WLAN standard. As part of building a PN involving many wireless communication standards, a scheme is proposed here for the integration of these two standards at MAC level. This work targets a dual mode device that is potentially capable of reconfiguring its air interface (MAC and PHY) depending on the communication requirements.**

Key words: WPAN, WLAN, integration, reconfigurability.

1. INTRODUCTION

The major driving forces for next generation wireless communication are personal services and convergence. The network will be more user-centric with emphasis on making the personal communication space more interactive. One approach is to start building from personal area networks (PAN) and integrate them with other infrastructure and legacy networks to achieve global connectivity.

One scenario which could be useful from the point of view of the above framework is the integration of wireless personal area networks (WPAN) with wireless local area networks (WLAN). Towards this, we investigate the possible integration of a prominent WPAN standard, IEEE 802.15.3 [1], with the popular WLAN standard, IEEE 802.11 [2]. This work aims at developing a scheme, at MAC level, for integrating IEEE 802.11 based WLANs with IEEE 802.15.3 based piconets. We target a dual mode device with both the 802.11 and 802.15.3 air interfaces (MAC and PHY). The proposed scheme provides synchronization and channel time allocation mechanisms for the operations of integrated network. The dual mode device (DDEV) can reconfigure its air interface depending on whether it operates in the WLAN mode (MODE 1) or WPAN mode (MODE 2). DDEV operates in two separate frequency channels for the two modes. It operates in one mode at a time. IEEE 802.15.3 provides channel plans for co-existence with WLAN, but currently no plan for integrating the two networks exists. Integration of WLAN and WPAN will facilitate WPAN devices (DEV) to gain access to the wired backbone via WLAN access point (AP) and also communicate with WLAN stations (STA). The targeted scenario is illustrated in Figure 1.

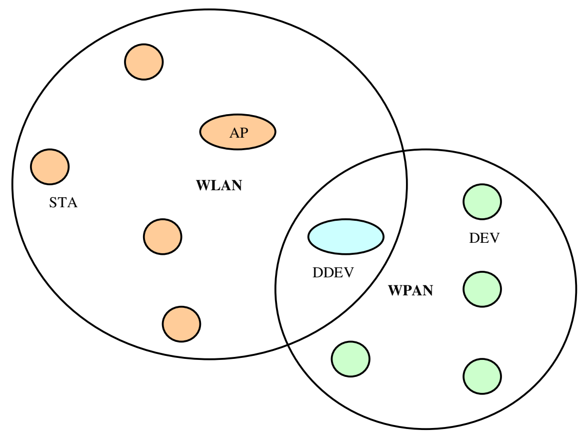


Figure 1: An integrated WPAN-WLAN network

Sections 2 and 3 present an overview of the 802.15.3 and 802.11 MAC protocols respectively. Section 4 presents the mechanism to establish and operate the integrated network. The data transfer mechanism is described in Section 5. Section 6 presents the simulation results and analysis. We conclude with Section 7.

2. IEEE 802.15.3

The IEEE 802.15.3 standard provides MAC and PHY specifications for WPAN. This protocol is used to convey information at high data rates amongst users in a geographically small area (~ 50m). This can be achieved through small, low power devices and with little or no infrastructure as specified in the standard.

An 802.15.3 network (piconet) consists of devices, one of which assumes the role of a controller. This controller, also referred to as the piconet controller (PNC), is the overseer of the network. The PNC allocates device IDs (DEVID) to the piconet members and allocates time slots for flows that require guaranteed channel access for transmission. The time slot allocation can be on a first come first serve or priority based.

For communication, the channel is divided into superframes. The superframe consists of three parts, namely the Beacon, the Contention Access Period (CAP) and the Channel Time Allocation Period (CTAP). Each superframe begins with a beacon, which serves a number of purposes. These include, synchronizing all the DEVs, broadcasting the piconet information to the rest of the piconet and conveying channel time distribution to the piconet members. The CAP is an optional part of the superframe, whereas the CTAP must be present. Each time slot in the CTAP is termed as channel time allocation (CTA). The CTA can be used for asynchronous and isochronous data streams as well as command frames. The CAP, on the other hand, may be used for commands and asynchronous data. Figure 2 gives a picture of the 802.15.3 superframe structure.

<table>
<tr><td rowspan="2">Beacon</td><td rowspan="2">Contention Access Period</td><td colspan="5">Contention Free Period</td></tr>
<tr><td>CTA 1</td><td>CTA 2</td><td>CTA 3</td><td>------</td><td>CTA n</td></tr>
</table>

Figure 2: 802.15.3 Superframe

In the CAP, various DEVs are permitted to contend for channel access in which they may transmit data to any other DEV. This contention is done using the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) algorithm. A DEV may contend to use whatever part of the CAP that is remaining in a particular superframe, but may not send data beyond the CAP timing, which is specified in the beacon. Once the CAP is over, the CTAs come into effect.

The CTA is a time slot given, by the PNC, to a particular flow. In this time slot, the flow is given uninhibited access to the channel in which no other flows will be present. The duration of the CTA depends on the time requested by the transmitting DEV. In short, this part of the superframe is based on the time division multiple access (TDMA) principle. There are two types of CTAs, viz, the dynamic CTA, and the pseudo-static CTA. The PNC can move a dynamic CTA within a superframe, on a superframe to superframe basis. This allows for flexibility in the PNC's scheduling to accommodate new flows. Dynamic CTAs can be used for asynchronous as well as isochronous streams. Pseudo-static CTAs are used only for isochronous streams. Once defined, such a CTA can be modified only by changing the CTA blocks in the beacon. A good simulation study of the 802.15.3 MAC is provided in [3].

3. IEEE 802.11

The IEEE 802.11 protocol provides MAC and PHY specifications for WLAN providing coverage of around 100 meters. An 802.11 based WLAN can operate in infrastructure or independent ad-hoc mode. Infrastructure WLAN is controlled by an access point (AP) whereas an independent WLAN works in an ad-hoc fashion. The channel access can be either contention based or polling based. The basic channel access scheme is termed as the distributed coordination function (DCF) whereas the polling based access is called point coordination function (PCF). DCF is based on the CSMA/CA algorithm while the PCF operates using TDMA. The AP coordinated infrastructure WLAN can operate with a contention based as well as contention free access mechanisms. Figure 3 gives a picture of the infrastructure based 802.11 super frame marking the contention free and contention based periods.

In the contention free period (PCF), the point coordinator coordinates channel access. Generally the point coordinator resides in the AP. The AP polls all the pollable stations for data. Not all stations are polled; instead the devices that intend to be polled get themselves registered with the AP at the time of association. The AP can poll the stations in a round robin or priority based fashion. Polling makes high QoS data transfer feasible. AP coordinated network gives the stations the option to access the wired backbone.

Contention based access is governed by the CSMA/CA algorithm. The stations perform a random backoff if the channel is found to be busy. This ensures that the transmissions from any two stations do not coincide and lead to loss of data. The contention period is primarily used for exchanging asynchronous data. An analytical and simulation study of 802.11 MAC is provided in [4].

<table>
<tr><td rowspan="2">Beacon</td><td colspan="4">Contention Free Period (PCF)</td><td rowspan="2">Contention Access Period (DCF)</td></tr>
<tr><td>Poll STA 1</td><td>Poll STA 2</td><td>-</td><td></td></tr>
</table>

Figure 3: 802.11 Superframe

4. Establishing And Operating The Integrated Network

This section presents the mechanism by which a WPAN integrates with the WLAN. There can be three possible situations under which the integrated network is established:

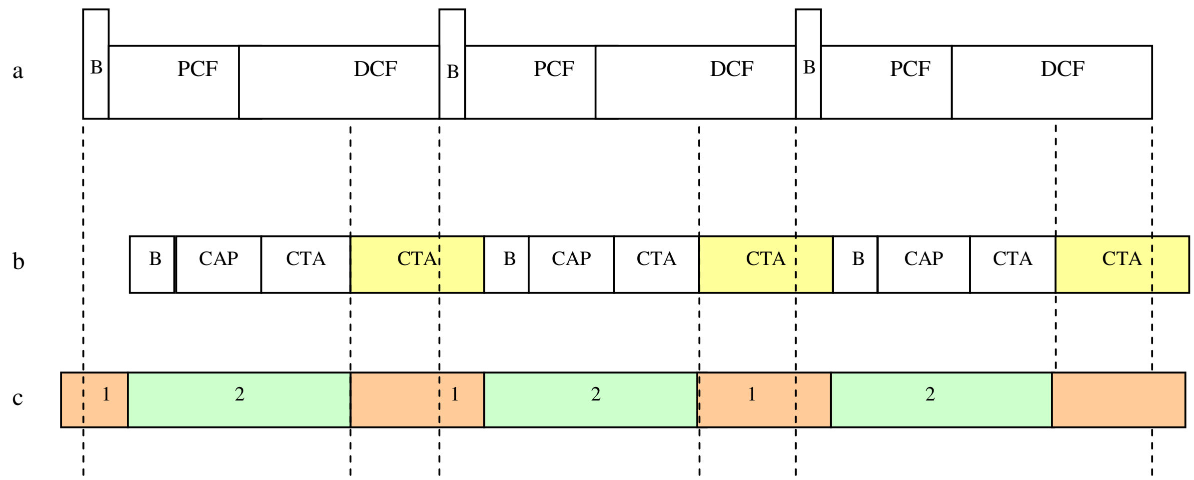


Figure 4: Superframe formats for the two modes of operations. (a) WLAN superframe format. It depicts the beacon, PCF and DCF slots. (b) Superframe format for the WPAN. The colored CTAs indicate that no flow to or from DDEV can be scheduled as it is in MODE 1. (c) DDEV modes for each time slot of the WPAN superframe

a) The user with an active WPAN enters an area which already has an operational WLAN. The user joins the WLAN and integrates the WPAN with it.

b) The user enters an area with an operational WLAN with his/her WPAN-WLAN compliant devices. The user joins the WLAN and subsequently starts a WPAN.
c) The user is already connected to WLAN and wants to start a WPAN.

The situations listed above lead to a common two step process for establishing the integrated network:

Step 1: Synchronization with the WLAN AP beacons.
Step 2: Establishing the WPAN superframe.

The underlying mechanism for superframe scheduling is the ultimate driver for the success of the integrated system. DDEV participates in the WPAN superframe depending on its channel time requirements for Intra-WPAN and WPAN-WLAN communication. DDEV has to ensure that it synchronizes with the WLAN beacon as well as the WPAN beacon. Whenever DDEV is in MODE 1, it ensures that no time slot in the WPAN is scheduled for any transmission to or from itself. It should also intimate the WPAN controller (PNC) that it would be in sleep mode during the time it is in MODE 1. Similarly, whenever DDEV is in MODE 2, it should inform the AP about it being in the sleep mode for WLAN. This sleep mode intimation helps to keep the protocols untouched by not adding any new messaging. Figure 4 depicts a scenario giving a superframe structure for WPAN with slots allocated for WLAN participation. DDEV can get slots scheduled for WLAN participation in a periodic or on-demand fashion. As shown in Figure 4(b), the colored channel time allocation (CTA) slots are reserved for DDEV to participate in WLAN. Hence, these CTAs cannot be scheduled for flows to or from the DDEV for communication within the WPAN. Here, we assume that DDEV participates only in the distributed coordination function (DCF) of the WLAN superframe.

5. DATA TRANSFER

As mentioned before, there can be two kinds of data transfer in the integrated system, namely, intra WPAN and WLAN-WPAN. An important issue that needs to be considered is the addressing scheme for the integrated network. Both 802.15.3 and 802.11 follow different schemes for device identification. All devices in a WPAN get a DEVID at the time of association by providing the PNC with their unique MAC address. All communications within WPAN take place using these DEVIDs. On the other hand, communications in WLAN use the MAC addresses of the associated devices. The different addressing schemes limit the possible communications in the integrated system.

In order to facilitate seamless communication between devices in the integrated network, we propose the following addressing structure without disturbing the original protocols. Whenever a new station joins WLAN, the AP and the PNC announce the signatures of the associated STA. DDEV maintains a list of MAC addresses of all devices associated with WLAN and WPAN. It assigns DEV IDs to all devices in the list, as shown in Table 1. Using the proposed scheme, DEVs know about the presence of STAs. Whenever, a DEV wants to communicate with another DEV, it makes use of the DEV IDs but when a DEV wants to communicate with a STA, it sends the data to DDEV which forwards it to the WLAN by using the corresponding MAC address. On the other hand, if a STA wants to transfer data to a DEV, it sends a route request to locate the corresponding DEV. DDEV, upon receiving such a request (when in MODE 1), informs the STA that the queried DEV is at one-hop distance from it, and it forwards the data to the DEV by using the DEV ID that corresponds to the receiver MAC address.

6. SIMULATION RESULTS AND ANALYSIS

We now present some simulation results an analysis of the expected performance of the scheme. All simulations have been performed using ns2 [5]. Some of the performance parameters that need to be looked at are:

a) Effect of the time spent by DDEV in MODE 1 on the performance of WPAN traffic.
b) Effect of the time spent by DDEV in MODE 2 on the performance of WLAN traffic.

Figure 5 shows the graphs for delay incurred by an MPEG4 flow in WPAN due to the DDEV being in MODE 1. The MPEG4 flow was scheduled for the DDEV; hence it could not be scheduled when the DDEV was in MODE 1, resulting in the increase in delay. We compare this delay with the case where the DDEV is in MODE 2 all the time. In such a case this flow could get a larger CTA and hence, this delay is smaller as evident from Figure 5. The simulation parameters are listed in Table 2.

Figures 6(a) and (b) show the delay and job failure rate (JFR) incurred by a DDEV bound WLAN flow based on the time it spends in MODE 1. We define JFR as the percentage of the total number of packets queued up at the transmitter MAC that is delivered to the receiver successfully. Simulation parameters are listed in Table 3. We see that as the duration of CTA increases, the delay as well as the JFR decreases. This can be attributed to the increase in the time a flow gets to transfer its data. Also, since the WLAN participation is solely assumed to be in the DCF, the contending flows get more time to contend as the time spent in MODE 1 increases.

Table 1: Internal table for addressing

Device Type	MAC Address (48 bit)	DEV ID
STA	--	1
DEV	--	2
STA	--	3
STA	--	4
STA	--	5

Table 2: Simulation parameters for WPAN performance measurements when DDEV in MODE 1

Parameter	Value
WLAN superframe size	30ms
WLAN PCF duration	10ms
WLAN DCF duration	20ms
WPAN superframe size	30ms
Duration of CTA of interest	12ms (fixed)
Duration for MODE 1	5 – 12ms
Traffic type	MPEG4
Data rate	1 Mbps

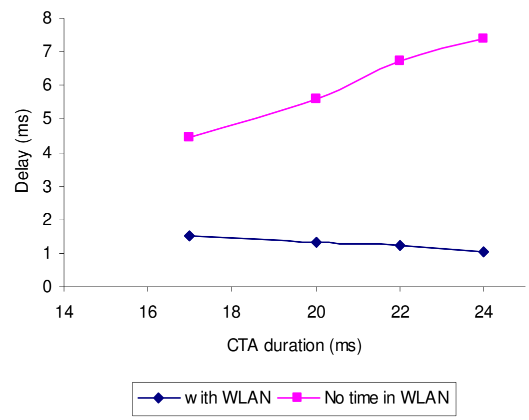
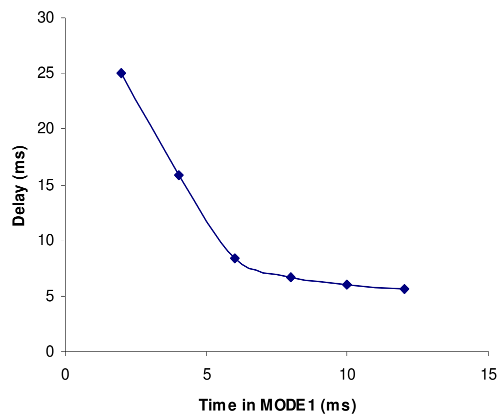


Figure 5: Performance curves for a WPAN flow with DDEV in MODE 1

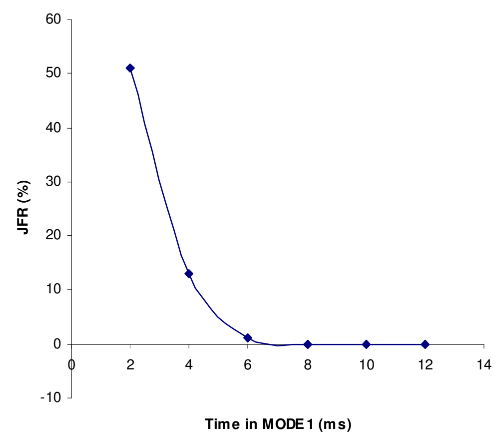
The simulation results show that the time duration DDEV spends in either of the modes has a bearing on the performance of the flows to or from DDEV. Hence, the scheduling schemes housed in the PNC need to be fair enough to maintain the required QoS for both WLAN and WPAN.

Table 3: Simulation parameters for WLAN performance measurements when DDEV in MODE 2

Parameter	Value
WLAN superframe size	30ms
WLAN PCF duration	10ms
WLAN DCF duration	20ms
WPAN superframe size	30ms
Time in MODE 1	2 to 12 ms
Traffic type	Constant Bit Rate
Data rate (for each flow)	2 Mbps
No of contending flows	10



(a)



(b)

Figure 6: Performance curves for traffic from the DDEV in MODE 1 with varying MODE 1 duration

7. CONCLUSIONS

In this paper, we have presented a scheme, at MAC layer, for facilitating integration of WPAN with WLAN. This is focused towards the feasibility of a dual mode device incorporating both the mentioned air interfaces, with any one mode active at a time. This enables reconfigurability and software defined radio (SDR) approach for the implementation of the device. This is achieved without adding any new messages or modifying existing messages in respective standards. From a study of this scheme, we see that an efficient way of integrating WPAN with WLAN can be devised for realizing the envisioned personal networks. Further studies need to be done to study the impact of reconfigurability and fine tune the scheme further. This work has not targeted the aspects of reconfigurability involved with the dual mode device and is a topic for future research.

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