Dual GSM/WLAN Mobile Terminal Modelling

Ion Bogdan, Ciprian-Romeo Comşa

Technical University of Iaşi

Abstract: The paper presents a simulation model as a finite state machine for a mobile terminal supporting simultaneously both GSM voice communications and data transmissions in an IEEE 802.11b WLAN network and we integrated this model in a simple IEEE 802.11b WLAN network to monitor the dual WLAN and GSM station behavior. Simulation results of the model checking in a networking environment are reported. The simulation model developed using Simulink Stateflow is of great help in studying the opportunity of using a Dual Station including both WLAN and GSM standards on a single chip.

Keywords: GSM network, WLAN 802.11, traffic modelling, simulation.

1. INTRODUCTION

This paper presents the guidelines for the modelling of a mobile terminal operating simultaneously in a wireless 802.11b local area network (WLAN) for data traffic and in a GSM network for voice communications (DualSTA). The model uses a finite state machine representation of the mobile terminal that has one single receiver and one single transmitter, thus not being possible receiving and/or transmitting simultaneously in both of the networks. The simultaneous communications in both of the networks is only apparent to the user: the communications actually take part separately in interleaved disjoint time slots. Also, because GSM is a TDMA standard and the mobile terminal has to fulfil specific tasks (receive, transmit or measure) in time slots prescribed by network, unconditional priority is given to the GSM communication. There is however one exception, which is the Beacon receiving in the 802.11b network, which blocks, if necessary, any GSM operation.

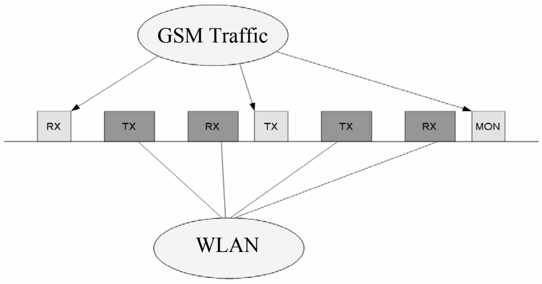

Fig. 1. WLAN and GSM traffic interopperation.

The WLAN and GSM traffic interoperation schematic is shown in Fig. 1 where the WLAN packets are placed between GSM slots.

2. RELEVANT 802.11b STANDARD SPECIFICATIONS

The 802.11 LAN is based on a cellular architecture, where the system is subdivided into cells. Each cell is controlled by a station called Access Point (AP). The functionality of a WLAN is assured by the Medium Access Control (MAC) layer, which can be constructed as a set of diverse services to accomplish information exchange, power control, synchronization and power control.

The basic access mechanism, called the Distributed Coordination Function (DCF) is basically a Carrier Sense Multiple Access with Collision Avoidance mechanism and it is used together with a Positive Acknowledge (ACK) scheme (Heiskala and Terry, 2002). DCF works by a station willing to transmit data, senses the medium first. If the medium is busy, then the station defers its transmission to a later time, but if the medium is free for a specified time (called Distributed Inter Frame Space (DIFS)), the station transmits. The receiving station then checks the CRC of the received packet and sends an acknowledgement (ACK) packet. This receipt indicates to the transmitting station that there were no collisions detected. If the sender does not receive ACK, then it retransmits the last fragment (Nedeltchev, 2001; Belanger and Diepstraten, 1996).

In order to reduce the probability of two mobile stations (STA) colliding because they cannot hear each other, the standard defines a Virtual Carrier

Sense mechanism: a STA wanting to transmit a packet first transmits a short control packet called Request To Send (RTS), which includes the duration of the following transaction (that is the packet and the respective ACK), the destination STA responds (if the medium is free) with a response control packet called Clear to Send (CTS), which includes the same duration information (Heiskala and Terry, 2002). All STAs receiving either the RTS and/or the CTS, set their Virtual Carrier Sense indicator (called Network Allocation Vector – NAV), for the given duration, and use this information with the Physical Carrier Sense when sensing the medium (Nedeltchev, 2001).

The diagram from Fig. 2 shows how the RTS/CTS mechanism works for station A as a transmitter and station B as a receiver and the NAV settings for their neighbours (Nedeltchev, 2001).

Bit error rates on wireless systems (10^{-5}-10^{-6}) are substantially higher than wire-line systems (10^{-12}). Thus, large blocks may approach the number of bits where the probability of a block error occurring may be extremely high. To reduce the possibility of this happening, large blocks may be fragmented by the transmitter and reassembled by the receiver node. While there is some overhead in doing this – both the probability of an error occurring is reduced and, in the event of an error, the re-transmission time is also reduced (Heiskala and Terry, 2002).

802.11 Specifications require for a Data volume to be transmitted to be split in units denoted as MAC Service Data Unit (MSDU) and allow for every MSDU to be split in smaller units denoted as MAC Protocol Data Unit (MPDU) (IEEE 802.11, 1999). The transmission of an MSDU consists in successive transmissions of its MPDUs. Every MPDU transmission should be acknowledged by the receiving part. The Short Inter Frame Space (SIFS) time intervals separate the receiving of an MPDU and the transmission of its ACK as well as the receiving of an ACK and the transmission of the next MPDU. The unacknowledged MPDUs are retransmitted after an AckTimeOut waiting time.

In good propagation conditions the transmission of an MSDU is a continuous succession of the sequence MPDU–SIFS–ACK–SIFS. The transmission of a second MSDU is allowed only after applying the basic access procedure. This way a STA having a huge volume of data to send is not allowed to block the channel for a too long period of time.

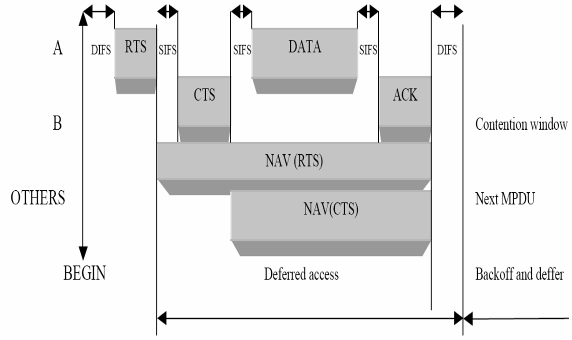

Fig. 2. NAV state for the RTS/CTS mechanism.

There are defined some types of inter frame spaces, illustrated in Fig. 3, in order to provide different priorities to stations (Belanger and Diepstraten, 1996): (1) Short Inter Frame Space (SIFS) is used to separate transmissions belonging to the single dialog (Fragment-ACK) and it is the minimum inter frame space. There is, at most, one single station to transmit at any given time, therefore giving it priority over all other stations. (2) Point Coordination IFS (PIFS) is used by the Access Point to gain an access over the medium before any other station. The value is SIFS plus one slot time. (3) Distributed IFS (DIFS) is the inter frame space for a station willing to start a new transmission, calculated as PIFS plus one slot time.

Backoff is a well-know method used to resolve contention between different stations waiting to access the media (Nedeltchev, 2001). This method requires each station to choose a random number between 0 and a given limit (CW – Contention Window), and wait this number of slot times before accessing the medium. The slot time is defined as a way a station will always be capable of determining if another station has accessed the medium at the beginning of the previous slot. It reduces the collision probability by half. Each station listens to the network, and the first station to finish its allocated number of slot times begins the transmission. If any other station hears the first station talk, it stops counting down its backoff timer. The network idle again, it resumes the countdown.

The 802.11 standard (IEEE 802.11, 1999) defines an exponential backoff algorithm which must be executed in the following cases: when the station senses the medium before the first transmission of the packet, and the medium is busy; after each retransmission; and, after a successful transmission. The only case when this mechanism is not used, is when the station decides to transmit a new packet and the medium has been free for more than DIFS.

On a WLAN infrastructure, the stations are kept synchronized by all the STAs updating their clocks according to the AP's clock, using the following mechanism: the AP periodically transmits frames called Beacon frames. These frames contain the value of the AP's clock at the moment of transmission. The receiving STAs check the value of their clocks at the moment the signal is received, and correct it to keep in synchronization with the AP's clock. Beacon frames are intended to be transmitted at regular time intervals (BP – Beacon Period), but the transmission of a particular Beacon could be delayed if the medium is busy at the intended moment (TBTT – Target Beacon Transmission Time) (IEEE 802.11, 1999).

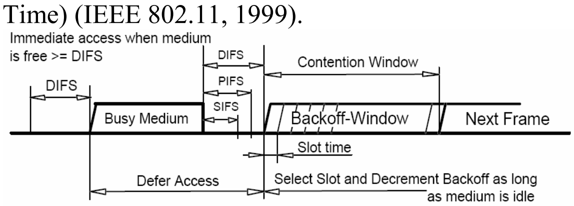

Fig. 3. A schematic of the access medium.

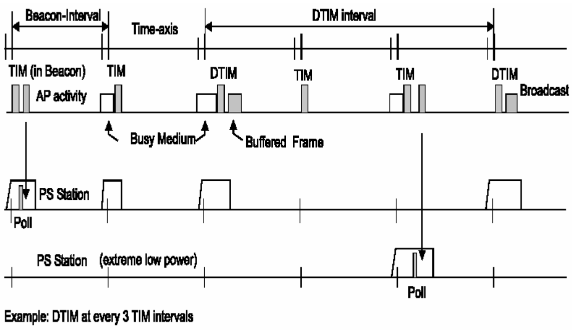

Fig. 4. Power management of one STA.

In mobile applications, battery power is an important resource. This is the reason why the 802.11 standard directly addresses the issue of power saving (PS) and defines a mechanism which enables STAs to go into sleep mode for long periods of time without losing information, as exemplified in Fig. 4. The main idea behind the PS mechanism is that the AP maintains a continually updated record of every STA working in PS mode, and buffers the packets addressed to it until the STA either specifically request the packets by sending a polling request (PsPoll message) or it changes its operation mode.

As part of its Beacon frames, the AP also transmits information (TIM – Traffic Indication Map) about which PS STAs have MSDUs buffered at the AP. The STAs wake up in order to receive the Beacon frame. If there is an indication that there is an MSDU buffered at the AP waiting for delivery, then the STA stays awake and sends a PS Poll message to the AP to get this MSDU. Some Beacon frames, regularly distributed in time, are followed by multicast and broadcast messages. These Beacon frames are denoted as DTIMs (Delivery TIM).

3. SIMULATION MODEL AND RESULTS

The main state diagrams of the modeled Power-Saving Station (Ps_STA) are presented in the followings. The initial state of a normal Ps_STA is DOZE. There are two conditions for exiting (wake-up) this state:

A. First is if the STA has to wake up to listen to the network activity and there are two situations: (1) When approaching a TBTT scheduled for wake-up (according to STA Listen Interval): a waiting state (WaitBcBMData) is activated and the channel state is monitored. The STA transits to RECEIVE state any time the channel becomes Busy. When exiting this state the packet is checked for errors. If there are errors in receiving it the STA discards the packet and returns to the WaitBcBMData state in order to receive the next packet. When the received packet is valid (FCS=1) its type is established through successive conditional transitions. If the packet is Beacon, its TIM part is analyzed to check for possible data stored in the AP having the STA as the final destination. (2) When approaching a DTIM beacon: at DTIM moments, the STA continues to wait after the Beacon for the broadcast data.

In both cases, if the received packet is of type Data STA checks for its final destination discarding it if the STA is not the intended destination or interpreting it, otherwise. If the Data are intended for the STA it stores the information, waits for a SIFS time and sends an ACK. If the received packet is an ACK the STA waits for a SIFS time and sends the next packet (MPDU) if there are still Data to transmit (Dts=1) or returns to DOZE state (Dts=0). Dts is an internal parameter used to indicate the application has still data to be transmitted by the STA. The transition to DOZE state is postponed if there are still Data to receive from the AP (DtR=1).

When the TIM element in the Beacon signals the existence of an MSDU having the STA as the destination (DtR=1) the STA sends a PsPoll message. This message is sent after a DIFS time if it is the only STA to receive a message, or by activating the back-off procedure if there are messages waiting for more than one STA. If, after a scheduled waking-up, neither a Beacon, nor an expected broadcast data packet is received, the STA returns to the WaitBcBMData state until these events happen.

B. The second condition for the station to wake up is the need to transmit data from a higher-level application, that is transmission of an MSDU (Dts=1). These moments are randomly generated following an exponential distribution. The basic access procedure is activated for the transmission of the first MPDU and successive SEND-SIFS-ACK-SIFS transitions are used until the entire MSDU is sent towards AP. The STA waits for an ACKTimeOut time for an ACK. It repeats the transmission of the last MPDU if the waiting time is longer than this.

Based on the GSM standard features (3GPP, 2004) and aiming at using a worst case analysis the following rules were adopted in building the GSM part of a mobile transceiver (Dual Station).

There are 4 possible operational states for an MS (Mobile Station): SEND, RECEIVE, MEASURE and SILENT. While in SEND state the MS transmits towards its own BS on the allocated frequency and time Slot. During the RECEIVE state the MS receives the information transmitted by the BS (Base Station) on the allocated frequency and time Slot. In the MEASURE state the MS tunes itself to the frequencies broadcast by the network and takes measurements of the local electromagnetic field strength. Finally, the SILENT state is the time period when the MS has no task to fulfil.

The Ps_STA part of the Dual STA has to have some supplementary features in order to interact with the GSM part. As the GSM standard is a pure implementation of the TDMA concept mobile terminals has to obey all the control commands it receives from the network like to transmit and to receive on the frequency channel and the time slot allocated by the network. As a consequence a dual terminal has to treat its tasks in the GSM network with greater priority than the ones in the WLAN. The sole exception is the receiving of the Beacon, which has absolute priority on all the events in GSM part.

The reason of implementing this exception is that after loosing a Beacon due to a simultaneous GSM task the Dual station continues to wait the Beacon all the time interval until the next Beacon, thus blocking all its traffic activity in the WLAN network. This has a great negative influence on its throughput and on its power saving efficiency. Loosing a slot or even two successive slots in GSM network has no other consequence than stealing a very small part of the voice traffic with little effect on its intelligibility.

The absolute priority given to GSM events means that any WLAN activity could be interrupted in the following situations: MPDU transmission, ACK transmission, PS Poll transmission, RTS transmission, Backoff, Receive, Waiting states. This behavior is obtained in the model by setting a variable (ExitGsm) anytime a WLAN state is abnormally terminated. The GSM part of the Dual STA contains, also, an extra state (GsmBusy) as compared to a normal STA in order to take into account this new feature.

An example of how a DualSTA transmission occurs is presented in Fig. 5. Shortly after 0.212s moment DualSTA sends an ACK for a previously received MPDU but it cannot continue to receive the next MPDU in the row as its operation is blocked by the appearance of an active GSM slot. The DualSTA enters in the GsmBusy state and frees the WLAN channel for a time interval greater than DIFS. Coming back from the GsmBusy state the DualSTA has to launch again a PsPoll asking for the remaining data in the AP buffer. It receives a new MPDU, acknowledges its receiving, but it can not receive the entire next MPDU as it has to transit again in the GsmBusy state. This time it looses the WLAN channel for more than a GsmBusy state duration as the STA5 was in Backoff state, its counter reaches the 0 value during the GsmBusy state of the DualSTA and, as consequence, it begins its own data transmission towards AP, of course by triggering the RTS/CTS procedure. By taking a closer view of the general picture in Fig. 5, one can see that this DualSTA transmission is interrupted, also, by STA2, then by STA5 again (twice in row), as well as by STA3 (also, twice).

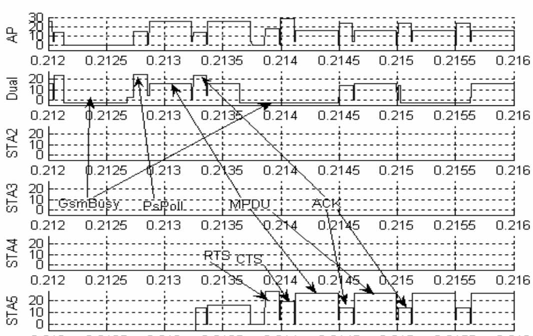

Fig. 5. An example of activity in the simulated network.

4. CONCLUSIONS

A Simulink stateflow model was built for a dual mobile terminal able to simultaneously communicate in a GSM network and in a WLAN network, but using a single transceiver unit. The simulation results revealed that the specifications of both of the standards, as well as the defined interactions between the two parts of the dual terminal were correct1y implemented into the model and this one can be used for future evaluation of the throughput and transmission delay of the dual terminal.

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