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Dual GSM/WLAN Mobile Terminal Modelling

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Abstract. *The paper presents the guidelines for the modelling of a mobile terminal operating simultaneously in a wireless 802.11b local area network (WLAN) for a data traffic and in a GSM network for a voice communication (DualSTA), as well as the model itself. A finite state machine representation of the mobile terminal that has one single receiver and one single transmitterwas used. Simulation results of the model checking in a network environment are reported.*

Keywords: GSM network, WLAN 802.11, modelling, simulation

1. Introduction

The present paper is intended for the modelling of a mobile terminal operating simultaneously in a wireless 802.11b local area network (WLAN) for a data traffic and in a GSM network for a voice communication (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; actually, the communications take part separately in interleaved disjoint time slots.

The paper is organized as follows: in the first part the GSM features are summarized and a Simulink sateflow model is presented for the GSM part of the DualSTA. Then the relevant 802.11b standard specifications are introduced and Simulink sateflow model is presented for the WLAN part of the DualSTA. Necessary interactions between the two parts and their caption into the model are also described. Finally, the operational checking of the model in a simulated network environment is made and the results are analyzed.

2. Overview of the GSM specifications

There are very strict rules [1] of communications in a GSM network and every communication entity is required to unconditionally obey them. There are two disjoint equal frequency bands allocated for the GSM networks, each of them divided in 200 KHz narrowband channels. The full duplex feature of a communication is obtained by using one 200 KHz channel in the lower band for a mobile station (MS) transmitting towards a base station (BS) and the channel with the same position in the higher band for BS transmitting towards MS. There are defined time Slots of 577 microseconds approximately (7500/13 precisely). 8 successive Slots on the same 200 KHz channel are grouped in a Frame (approx. 4.62 miliseconds), 26 Frames form a Traffic Multiframe (120 miliseconds, precisely) and 51 Frames form a Control Multiframe (approx. 235 miliseconds). There are two other hierarchical levels (superframe and hyperframe), but they are not relevant for our modelling. A BS maintains a precise time reference and broadcasts it in its own cell. The Slots on the channels of a BS are perfectly time-aligned, but there is no time synchronization among the BSs in a GSM network.

In active mode (engaged in a call) an MS uses time Slots with the same number (0 to 7) in successive Frames in order to receive from BS (forward or down link) and, also, time Slots with identical number on the frequency paired channel for transmitting towards BS (reverse or up link). So, a traffic channel is the succession of Slots with identical no. on two paired frequencies. In order for an MS not to receive and transmit simultaneously, the Slot numbering for the uplink is displaced by 3 slots (see Figure 1).

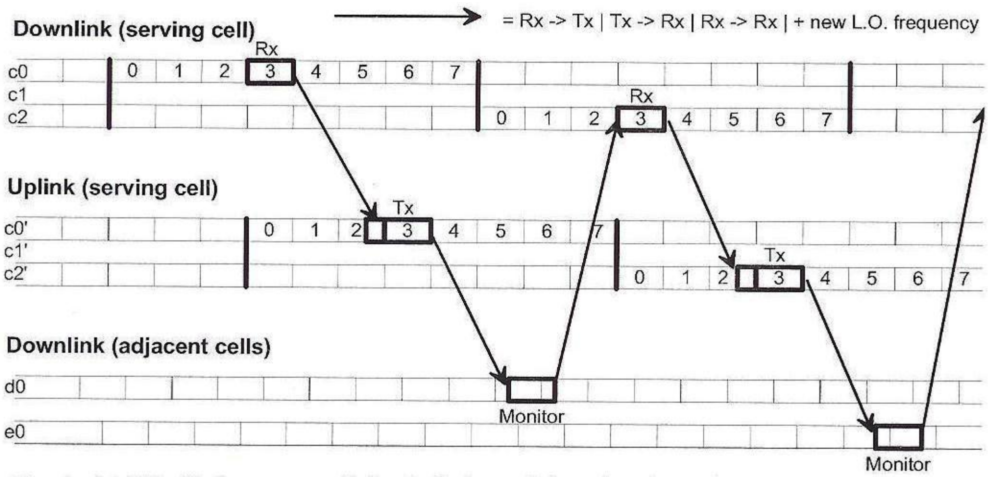

Fig. 1. Mobile Station usage of physical channel timeslots (For a full-rate hopping traffic channel assigned timeslot 3)

During the time interval from the end of the transmission Slot in a Frame to the beginning of the receiving Slot in the next Frame the MS is required to take measurements of the RF field strength level on specific channels. The actual time moment to take measurements is at the MS' choice. The duration of the measurements is a function of the total number of channels to be measured and of the time needed to take an accurate measurement on a given channel.

For power saving reasons an MS is allowed not to transmit during the allocated Slot if the voice signal is absent (Discontinuous Transmission mode - DTX). In order for the link to be kept alive by the network, while in DTX mode the MS is required to transmit a special bit sequence (SID - Silent Descriptor) in the allocated Slot during 8 successive Frames. The SID transmission is repeated every 4 Traffic Multiframe in Frames no. 52-59 as long as the voice signal is absent.

Every 13 Slots (twice in a Traffic Multiframe) the user data flow is interrupted: one of the Slots is used to carry control information associated with the interrupted data flow and the other one is 'reserved for future use'.

Common control channels are organized on a BS specific frequency denoted as the cell pilot frequency ('C0' or 'BCCH frequency' in GSM standard language) with a Control Multiframe periodicity. Usually, they are defined on the Slot no. 0, but Slots no. 2, 4 or 6 could be used in complex networks, too. The number of Slots used to carry control information is specified by the network through the value (1 - 4) of the BS_CC_CHANS parameter. The connected MS are assigned to a specific Slot no. based on their unique identity IMSI. The activity is independently organized on each of the activated Slot no. and, thus, its actual value does not influence the behaviour of a particular MS, except for a permanent time displacement of its control Slots.

The slots in Frames no. 0, 10, ..., 40 are used by MSs to adjust their own transmission frequency and form the frequency correction channel (FCCH). The slots in Frames no. 1, 11, ..., 41 contain a training sequence and are used by the MSs for the radio channel estimation. The slot in the last Frame (no. 50) is free. The slots in the remaining Frames carry the common control information and are dealt with in groups of 4. The group no. 0 (Frames no. 2-5) carries specific information for a given GSM network and is denoted as the BCCH channel (B - from Broadcast, as the information is broadcast by the BS on the entire cell area). The group no. 1 (Frames no. 6-9) is always used for Access Grant messages. The groups no. 2-9 are used as supplementary Access Grant channels (if necessary), Paging channels (PCH) and, possible, as SDCCH (these ones are special channels, temporary activated by a BS and used by its MSs at the beginning of a call).

For power saving reasons an MS in IDLE mode is required to monitor only one Paging Group in a Control Multiframe. The specific monitored group is computed by the MS based on its unique permanent identity (IMSI) and the total number of Paging Groups defined by the network. Moreover, a Paging group may not appear in every Control Multiframe, but only at every other BS_PA_MFRMS Control Multiframe. The value of the BS_PA_MFRMS parameter ranges from 1 to 7 and it is network specific. The time a MS spends by exchanging messages with the network is extremely small as compared to the time it remains silent. Thus, the influence of the BS_PA_MFRMS actual value does not significantly influence the simulation results.

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 scheme, as follows:

- A station (STA) wanting to transmit senses the medium. If the medium is busy then it defers transmission. If the medium is free for a specified time (called Distributed Inter Frame Space - DIFS), then the station is allowed to transmit.
- The receiving STA checks the CRC of the received packet and sends an acknowledgement packet (ACK). Receipt of the ACK indicates to the transmitter that no collision occurred. If the sender does not receive the ACK for a preset time interval (AckTimeOut) then it retransmits the packet until it receives the ACK or it discards the whole transmission after a given number of retransmissions.

It should be noted that the standard does allow the STA to transmit to a different address between retransmissions of a given fragment. This is particularly useful when an AP has several outstanding packets to different destinations and one of them does not respond.

In order to reduce the probability of two STAs 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 RTS (Request To Send), 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 CTS (Clear to Send), which includes the same duration information. All STAs receiving either the RTS and/or the CTS, set their Virtual Carrier Sense indicator (called NAV – Network Allocation Vector), for the given duration, and use this information together with the Physical Carrier Sense when sensing the medium.

It should also be noted that, due to the fact that the RTS and CTS are short frames, the mechanism also reduces the overhead of collisions, since these are recognized faster than if the whole packet was to be transmitted. (This is true if the packet is significantly bigger than the RTS, so the standard allows for short packets to be transmitted without the RTS/CTS transaction. This is controlled on a per STA basis by a parameter called RTS Threshold).

802.11 Specifications require for a Data volume waiting for transmission to be split in units of no greater than 2312 bytes denoted as MAC Service Data Units (MSDU) and allow for every MSDU to be split in smaller units denoted as MAC protocol Data Unit (MPDU). For a DSSS PHY the length of an MPDU should be between 14 and 4095 bits. The transmission of an MSDU consists in successive transmissions of its MPDUs. Every MPDU transmission should be acknowledged by the receiving part. The SIFS time intervals (see later) 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.

The standard defines 4 types of Inter Frame Spaces, which are used to provide different priorities:

- SIFS – Short Inter Frame Space, is used to separate packets belonging to a single MSDU transmission and is the minimum Inter Frame Space. This value is a fixed value per PHY and on the 802.11 DSSS PHY this value is set to 10 microseconds.
- PIFS – Point Coordination IFS, is used by the AP to gain access to the medium before any other STA. This value is SIFS plus aSlotTime (defined in the following), and on the 802.11 DSSS PHY this value is 30 microseconds.
- DIFS – Distributed IFS, is the Inter Frame Space used for a STA willing to start a new MSDU transmission, which is calculated as PIFS plus aSlotTime, i.e. 50 microseconds on the 802.11 DSSS PHY.
- EIFS – Extended IFS, which is a longer IFS used by a STA that has received a packet that it could not understand; its value is dependent on the transmission rate and the physical Preamble and Header (see the followings) durations.

Backoff is a method used to resolve contention between different STAs wanting to access the medium. The method requires each STA to choose a random number between 0 and a given limit (CW – Contention Window) and wait for this number of aSlotTimes before accessing the medium. The aSlotTime is defined in such a way that a STA will always be capable of determining if another STA has accessed the medium at the beginning of the previous aSlotTime. The value of aSlotTime is 20 microseconds in 802.11 DSSS PHY.

The 802.11 uses an exponential Backoff mechanism meaning that each time a STA collides, it will increase exponentially the maximum number (CW) for the random selection. The exponential Backoff algorithm must be executed in the following cases:

- when a STA senses the medium as Busy before the first transmission of a packet;
- after each MPDU retransmission, and
- after an MSDU successful transmission.

The only case when this mechanism is not used is when the STA decides to transmit a new packet and the medium has been free for more than DIFS.

STAs need to keep synchronization. On an infrastructure BSS, this is achieved 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. This prevents clock drifting which could cause loss of synchronization after a few hours of operation. 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).

Wireless LANs are typically related to mobile applications. In this type of application, battery power consumption is a significant issue. 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. 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 (PS Poll 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, so these 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). All PS STAs who wish to receive multicast and broadcast messages should wake up at every DTIM.

The payload (Frame Body) to be transmitted by a MAC unit (RTS, CTS, MPDU, ACK, PS Poll, etc.) is appended to a MAC Header and it is followed by a 4 byte CRC code (FCS – Frame Check Sum). The MAC Header includes mainly routing information and the NAV. Its length depends on the MAC unit type. FCS is used by the receiving STA to check for the packet integrity.

During transmission on the physical medium the MAC unit shall be appended to a physical layer preamble and header. Two different preambles and headers are defined: the mandatory supported Long Preamble and header (lasting for 192 microseconds), which interoperates with the current 1 Mbit/s and 2 Mbit/s DSSS specifications, and an optional Short Preamble and header (lasting only 96 microseconds). At the receiver, the Preamble and header are processed to aid in demodulation and delivery of the Data. The optional Short Preamble and header is intended for applications where maximum throughput is desired and interoperability with legacy and non-short-preamble capable equipment is not a consideration. That is, it is expected to be used only in networks of like equipment, which can all handle the optional mode.

5. The Simulink statelow model for the WLAN part

The WLAN part of a DualSTA is modelled as a PS STA [3]. The initial state of a normal PS STA is DOZE. There are two conditions for exiting (wake-up) this state:

A. The Station has to wake up to listen to the network

- *approaching a TBTT scheduled for wake-up* (according to PS STA Listen Interval): a waiting state (WaitBcBMData) is activated and the channel state is monitored. The PS STA transits to RECEIVE state any time the channel becomes Busy. When exiting this state the packet is checked for errors (FCS). If there are errors in receiving it the PS 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 PS STA as the final destination.
- *approaching a DTIM Beacon*: at DTIM moments, the PS STA continues to wait after the Beacon for the scheduled broadcast data.

- In both cases, If the received packet is of type Data, PS STA checks for its final destination discarding it if the PS STA is not the intended destination or interpreting it, otherwise. If the Data are intended for the PS STA it stores the information, waits for a SIFS time and sends an acknowledgement (ACK). If the received packet is an ACK the PS 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 PS 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 PS STA as the destination (DtR=1) the PS STA sends a PsPoll message. This message is sent after a DIFS time if it is the only PS STA to receive a message, or by activating the back-off procedure if there are messages waiting for many PS STAs. If, after a scheduled waking-up, neither a Beacon, nor an expected broadcast data packet is received, the PS STA returns to the WaitBcBMData state until these events happen.

B. The station has to wake up because it needs 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 message. It repeats the transmission of the last MPDU if the waiting time is longer than this.

6. Modelling interactions bewteen the two parts of the DualSTA

As the GSM standard is a pure implementation of the TDMA concept, a mobile terminal has to obey all the control commands it receives from the network, that is to transmit and to receive on the frequency channel and the time slot allocated by the network, to change them when the network commands this, to make field measurements and to report the results at specified moment of times, and so on. As a consequence a dual terminal has to treat its tasks in the GSM network with greater priority than the ones in the WLAN network. 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 with the following effects:

- *MPDU transmission*: a retransmission is necessary and this is triggered by not receiving the acknowledgement message;
- *ACK transmission*: the correspondent MPDU will be retransmitted, but the receiver is required to check its ordering number and it rejects the new packet as being a duplicate;
- *PS Poll transmission*: the AP could not intepret the message, it will not transmit any answer towards the DualSTA and this one will repeat the PS Poll transmission at a later time (according to the Specifications, this could be done "at the STA choice");
- *RTS transmission*: a CTS message will be not received because the AP does not understand the truncated RTS message and, thus, the RTS transmission is repeated;
- *Backoff*: the backoff process should be terminated, as the DualSTA could not continuously monitor the WLAN channel state during its GSM activity. But the reason of being in the Backoff state is remembered when coming back from the GSM and the Backoff procedure is reinitiated according to the WLAN rules.
- *Receive*: the CRC code (FCS bits in the 802.11 words) is not correct and the respective message should be retransmitted as it happens normally when CRC signals a bad reception;
- *Waiting states*: the next event is executed if a timeout is specified for it and its limit is not reached or the event is skipped otherwise with the usual consequences according to the Specifications.

This behaviour is obtained in the model by setting a variable (*ExitGsm*) anytime a WLAN state is abnormally terminated. The GSM part of the DualSTA contains, also, an extra state (*GsmBusy*) as compared to a normal STA in order to take into account this new feature. A Simulink stateflow diagram of the WLAN part of the DualSTA was built based on the above considerations.

7. Simulation: parameters and results

The simulation is aimed at evaluating the conformance of the mode with the specifications of the two standards. This is why the radio channel is considered as being perfect. Also, the simulation only evaluates the time superposition of the events in the two network, accounts for actions to be made in order to maintain both communications alive, and keeps records of the data volume exchanged in the WLAN. This is not a bit level simulation !

An infrastructure network is built around an access point (AP). It includes a DualSTA (STA no. 1) and 4 other normal STAs (no. 2-5). For an accurate monitoring of the traffic a STA transmits always towards the same STA in the network (obviously, by using the AP): STA1 to STA2, STA2 to STA3, STA3 to STA4, STA4 to STA5, and STA5 to STA1.

It is considered that the time origin in GSM network precedes the one in the WLAN by a random generated value between 0 and 104 GSM Frame duration (480 miliseconds), as this one is the greatest periodicity encountered among modelled GSM events. According to the 802.11 Specifications a DTIM should be transmitted by the AP at 0 time.

The MSDU volume is kept constant and equal to 7777 bits (about the half of the maximum allowed value). The fragmentation is activated and various values were used for the MPDU length.

The STAs (the Dual one included) uses the RTS/CTS procedure in order to initiate a transmission. The basic access procedure is used for the transmission of RTS message. The modelled AP is able to use the same RTS/CTS procedure in order to initiate a transmission, but in our simulation environment it only answers to PS Poll messages. The transmission rate of RTS, CTS, ACK and PS Poll messages is the same as the one used for the transmission of the MPDU and could be chosen from the values in the BSS basic rate set, that is 1, 2, 5.5 or 11 Mbits/second. This choice is facilitated by the 802.11b Specifications that request a STA joining an infrastructure network to be able to receive and transmit on any of the rate included in the BSS basic rate set.

If an MSDU transmission of the Dual STA is interrupted by a GSM event the continuation is done by invoking again the RTS/CTS procedure.

Short/Long Preamble choice could be made independently for each of the STAs. At this stage of the model the Preamble type could not be negotiated between a STA and the AP. So the simulations are run by using the same Preamble type for all the entities in the network.

The Figure 3 present typical time evolution of the 6 entities in the network. The following conventions are used in representing them as pulses:

- the pulse time position and duraton are identical with the actual values of the represented state's time position and duration, respectively;
- the pulse amplitude for the DOZE state is -5;
- the pulse amplitude for the GsmBusy state is -3;
- the pulse amplitude for the Backoff state is 0;
- the pulse amplitude for all of the waiting states is between 1 and 10, different values being used for different reasons of being in a waiting state: SIFS, DIFS, CTS, ACK, MPDU, Beacon, Broadcast data;
- the pulse amplitude for all of the receiving states is between 11 and 20, different values being used for different receiving messages: RTS, CTS, ACK, PsPoll, MPDU, Beacon, Broadcast data;
- the pulse amplitude for all of the sending (transmiting) states is between 21 and 30, different values being used for different sending messages: RTS, CTS, ACK, PsPoll, MPDU, Beacon, Broadcast data;

By observing the pulse amplitudes one can easily distinguish the entities communicating with each other at a given moment of time, as well as the state of the other entities.

From Figure 3 one can see that as the DTIM for all of the STAs is 3, all of the STA wake up when the simulated time is 0.1s and 0.4s. The are only transmissions from the STAs towards the AP until the first wake-up. One notes that the transmission time for equal MSDU lengths is greater for the DualSTA as compared to that of the normal STAs. Also, the first transmission of the DualSTA is interrupted by the transmission of STA5 and the second transmission of the DualSTA is interrupted by a transmission of the STA4.

After the first wake up of the STAs, STA3 is the first winner of the Backoff competition in order to receive messages from the AP. Then STA2, STA5, and STA4 follow in this order. Although DualSTA has data bufferred in the AP (STA5 transmitted 5 MSDUs before 0.1s and the destination is DualSTA) it can not launch a PsPoll to ask for receiving them as it did not receive the Beacon at 0.1s TIM, being in a GsmBusy state at that moment. Moreover it can not go to the Doze state after wake up at 0.1s time as it has to wait for the Beacon as the Specifications ask. It continues to wake all the Beacon period time interval until the next Beacon.

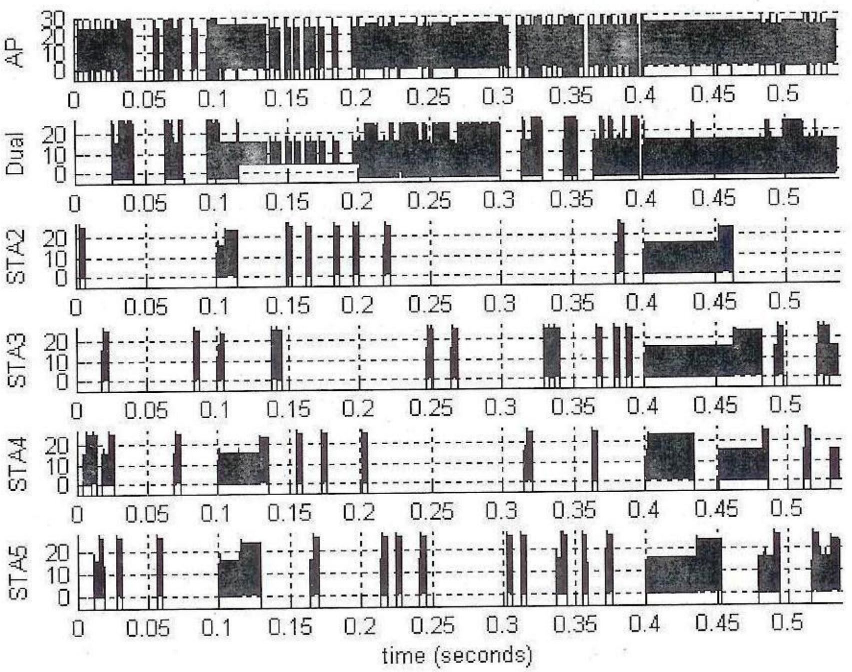

Fig. 3. An example of activity in the simulated network

Becoming aware of the data buffered in the AP at 0.2s moment DualSTA send a PsPoll and receives data from AP. The data exchange is interrupted by other STAs sending data towards AP, the interruption being facilitated by periodical appearance of GsmBusy states when WLAN channel becomes Idle.

The situation becomes even worse after the second wake up of the STAs at the 0.4s time when the other STAs have more data to receive from the AP, and, also, they have their own data to send towards AP.

An example of how the a DualSTA transmission occurs is presented in Figure 4. 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 receiveing, 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 Figure XXX, 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).

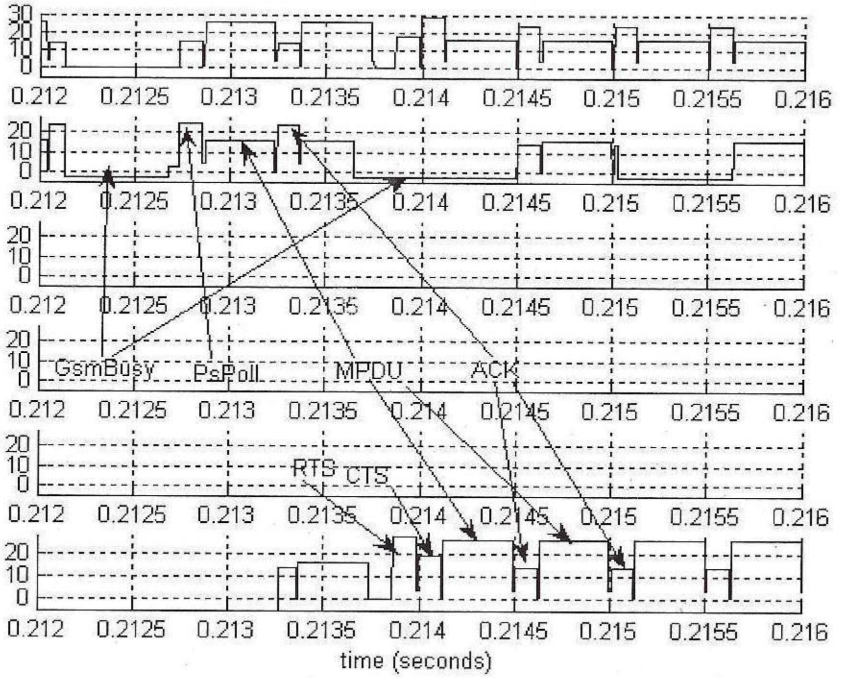

Fig. 4. A detail from Figure 3

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8. Conclusions

A Simulink stateflow model was built for a dual mobile terminal able to simultaneously communicate in a GSM network and in WLAN network, but using a single tranceiver 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 correctly 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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