LOW POWER ASIC DESIGNS FOR FAST HANDOFF IN IEEE802.11

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ABSTRACT
The Handoff process is a key problem in many wireless network processing applications. Current implementations of this process using software implementation are time consuming and cannot meet the gigabit bandwidth requirements. Implementing this process within the hardware improves the search time considerably and has several other advantages like reducing power consumption. In this paper we present an array based hardware implementation of this time consuming process for network mobility. A new mechanism for mobility management to minimize the handoff latency in IEEE 802.11 wireless local area network is also presented. Compared to the basis model and at 1GHz, this new mechanism allows a profit of 60% in power consumption and 20% in silicon area. Those two designs are described in VHDL at the RTL level language and implemented on an ASIC (Application-Specific Integrated Circuit) and are evaluated in terms of speed, area and power consumption.

Keywords: IEEE 802.11, Handoff, MAC, design, ASIC

1. INTRODUCTION

The world of WLANs is truly an exciting area, with major activity worldwide, challenging traditional service providers and business models. Initially, WLANs were meant to be an augmentation, not a replacement, of wired LANs and premises telephone systems. WLANs were deployed in enterprise or corporate locations where there might be a number of factors that limited or prevented wired systems from being installed. Today, we see much greater utility for WLANs, as evidenced by the emergence of thousands of hotspots around the world. In some cases, it is cheaper to deploy wireless in an office than to replace a crumbling old token-ring cable plant with shiny new Ethernet. In general, WLANs operate over short ranges, anywhere from 10 to 500 feet (3 to 150 m), so their coverage areas are microcells or piccocells.

Mobility is the most important feature of a WLANs system. Undoubtedly the future perspective of networking will demand to support mobile users traveling all over the world. In addition to that, the number of portable devices that need access to the Internet is exponentially increasing. Users on the other hand are no longer required to work in their company's home network while they may be moving from place to place. Usually, continuous service is achieved by supporting handover from one cell to another. Handover is the process of changing the channel (frequency, time slot, spreading code, or combination of them) associated with the current connection while a communication is in progress. It is often initiated either by crossing a cell boundary or by deterioration in quality of the signal in the current channel.

In IEEE 802.11 based wireless LAN, when the Mobile Terminal (MT) changes its point of attachment to the internet, it may produce a service interruption, since the MT cannot send or receive any packets from the time at which it disconnects from one point of attachment to the time at which it registers with a new point of attachment. Such an interruption would be unacceptable for real time services such as voice-over IP, which demands a further optimization of the mobility management in IEEE 802.11 based WLAN. Our motivation is to study the impact of the handoffs for delay of the sensitive applications. Our evaluation results show that the conventional handover is not totally effective for QoS requirements. So, we propose a hardware implementation for the handoff process in WLAN networks, using an ASIC circuit.

The paper will be organized as follows: in section 2, an overview of related works is provided. Section 3 presents an environment with a wireless communication based on IEEE 802.11 standard. In section 4, we describe the existing layer-2 handoff mechanism. Section 5, highlights the hardware implementation of handoff mechanisms (basis and proposed) for campus wide networks. Results are dealt in Section 6. Finally, section 7 is the concluding part of the paper.

2. RELATED WORKS

The literature contains several efforts proposing a mobility modeling and management approaches aiming at improving the handoff management and at optimizing resource reservations.

In (Choi C.H. et. al., 2002), the authors suggest the use of an adaptive bandwidth reservation based on a mobility graph and 2-tier cell structure to determine the amount of bandwidth to be reserved in the cell. Another resource reservation approach is presented in (Islam M.M. et. al., 2002) and (Islam M.M. et. al., 2003), where the authors propose a bandwidth reservation scheme that uses a mobility parameter-based resource reservation estimator function (RREF). This nonlinear function uses distance, direction, and velocity to calculate the probability of a MT visiting a particular cell. The authors, in (Liu T. et. al., 1998), propose a predictive mobility management scheme that models the MT, as a linear dynamic system driven by time varying forcing functions that simulate subjective moving intentions from the user and objective random perturbations from the environment. The mobility management model proposed in (Liang B. and Haas, Z.J., 1999), is based on Gauss–Markov model where an MT's velocity is correlated in time to various degrees in order to predict the future location of a MT. In (Hou, J. and Fang Y., 2001), authors initiated the idea of taking the mobility into account for call admission control algorithms. They explore many important points for mobility-based call admission control. They indicate that it is important to make the reservation at the appropriate time to save the reserved bandwidth.. In this model, the authors did not use the mobility history of the users to enhance the estimation accuracy. In (Yu, F. and Leung, V.C.M., 2002), a mobility-based predictive algorithm for call admission control was presented. This algorithm is motivated by a computational learning theory, which has shown that prediction is synonymous with data compression. The main limitation of this approach is that it is not applicable for a soft handoff, which makes this approach unsuitable for most of the existing and future mobile telecommunication. Moreover, this approach requires every adjacent Access Point (APs) to reserve the channels for all the users.

Based on the observation that the movement behaviors of the majority of people are performed repetitively process, the author in (Tabbane, S., 1995), models the user inter-cell mobility as a time-dependent (location, probability) pair. This work uses the probability that the user is found in a certain location during a given period of time as a base parameter. The (location, probability) pair is derived from the long-time observation statistics. While providing a good starting, enabling the regularity in a user's daily movement, Tabbane's model does not reflect an instantaneous movement behavior, and the (location, probability) pair is not totally efficient in representing the itineraries which are usually present in a user's movement pattern. As a possible solution to improve the call connectivity, the Current implementations of this process using software methods are time consuming and cannot meet gigabit bandwidth requirements. A few works have addressed the hardware implementation of the mobility in WLANs networks. The authors in (Chiang, M.H, 2006), proposed a design flow system and function module of active scan in WLANs. In (Zaidi, M et. al., 2008), we have proposed the hardware transformation and implementation of the handoff protocol from its initial software description. We have implemented two models that reduce Scan phase during the handoff execution. These models have been implemented on a FPGA circuit. Implementing this process in the hardware circuits improves considerably the search time and has several other advantages like the reduction of power consumption and the silicon area minimization.

3. HANDOFF PROCESS

The operation destined to change an association from one AP to another is known as a handover. Original design of the IEEE 802.11 standard (IEEE 802.11. Part 11, 1999), has just considered the handoff signaling in the wireless part. Figure 1 shows the main elements involved in a layer-2 handoff: the MT, the old AP, the new AP, and the distribution system (DS). It can be observed that basic service sets (BSS1 and BSS2) must belong to the same extended service set (ESS1). In the same way, radio channels of each cell (CHX, CHY) shall be none mutually interfering channels. The handover procedure can be divided into three phases: discovery, reauthentication, and reassociation (IEEE 802.11. Part 11, 1999) and (Mishra AS and Arbaugh W, 2003).

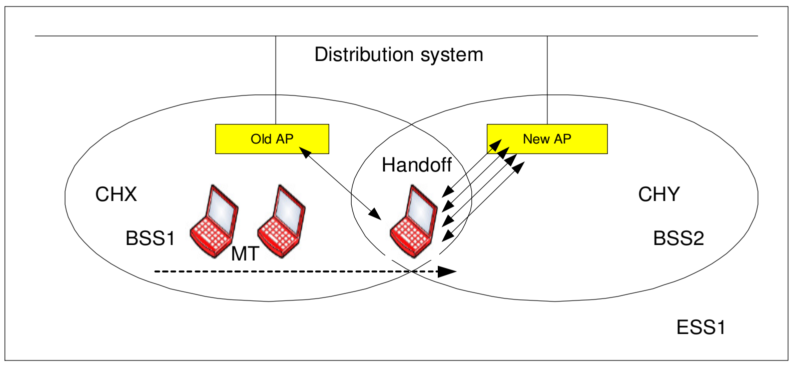


Figure. 1 Involved elements in the layer 2 handover

The discovery process involves handoff initiation and scanning phases. As signal strength and signal-to-noise ratio from a station's current AP get weaker, a MT loses connectivity and initiates a handoff. Then the client is not able to communicate with its current AP, so the client needs to find the other APs available. This scan function is performed at a MAC layer, and the station can create the available AP list ordered by the received signal strength.

For the scan phase, a MT can perform scan operation either in passive or active mode. In passive scan mode, using the information obtained from beacon frames, MT listens to each channel of the physical medium to try and to locate an AP. In the active mode (the wireless NICs do by default), as shown in Figure. 2, MT broadcasts additional probe packets on each channel and receives responses from APs. Thus the MT actively probes for the APs, and the actual number of messages varies from 3 to 11. Figure. 2 shows the sequence of messages typically observed during a handoff process. The handoff process starts with the first probe request and ends with a reassociation response from the new AP. The probe function follows the IEEE 802.11 MAC active scan function and the standard specifies a scanning procedure as follows.

1. Using CSMA/CA, acquire the access right to the medium.
2. Transmit a probe request containing the broadcast address as destination, SSID, and broadcast BSSID (Basic SSID).
3. Start a Probe Timer.
4. If medium is not busy before the Probe Timer reaches MinChannelTime, scan the next channel. Otherwise, process all received probe responses.
5. Move to next channel and repeat the above steps.

After all channels have been scanned, the informations received from probe response are scrutinized by a MT to select a new AP. Once the STA decides to join a specific AP, authentication messages are exchanged between the STA and the selected AP, and after a successful authentication, the STA sends a reassociation request and expects a reassociation response back from the AP.

4. HANDOFF ARCHITECTURE

In this section, we describe the hardware implementation of the Handoff process. We focus on the MAC receiver and transmitter part. Figure. 2 illustrates the system architecture. We try to divide handoff functions to 5 parts: a controller module, a selection module, a receiver part, a transmitter part and the SRAM with 256 words of 16 bits.

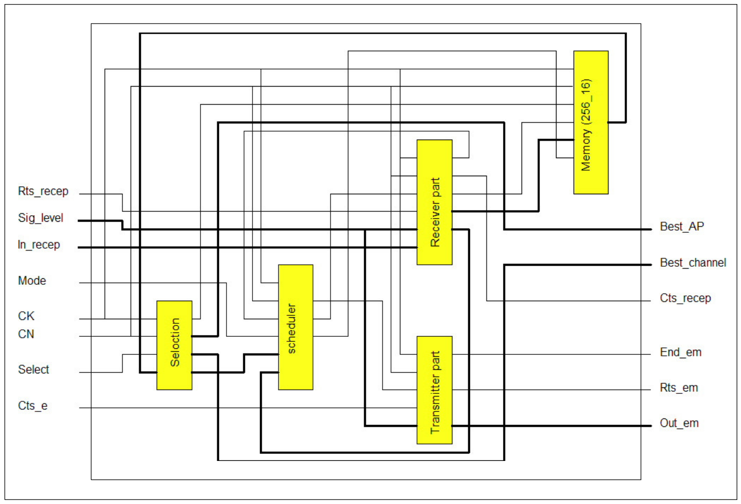


Figure. 2 Top level structure of the IEEE 802.11 Handoff

4.1. Existing layer-2 handoff mechanism

We are interested in using the handoff phases, according to models which offer a transparent transition from one AP to another within a minimum delay. The IEEE 802.11 a/b/g series offers a Wireless connectivity to the users at high rates. An AP provides connectivity for the mobile users.

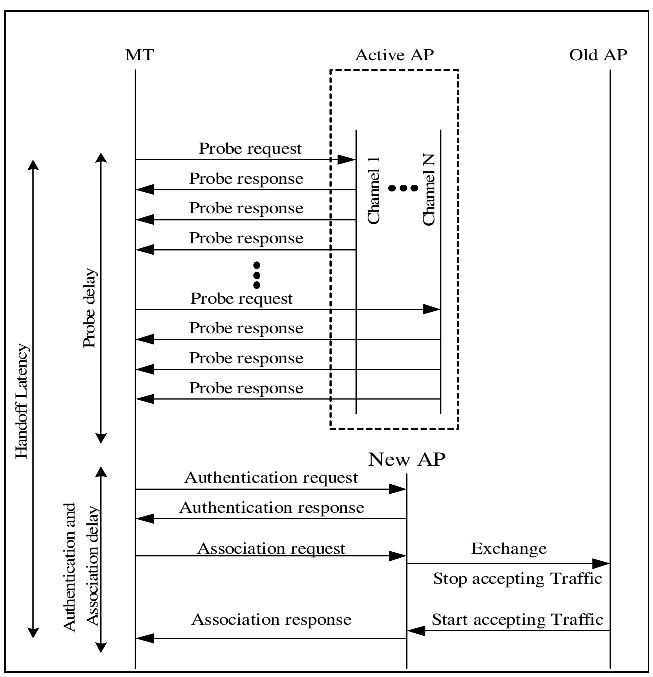


Figure. 3 Active discovery example

The 802.11 wireless devices allow the user to move freely between APs within, the coverage area, commonly known as the hotspot. The operation of changing from one AP to another AP is known as Handoff.

The conventional Handoff process is divided into three phases namely (a) Scan (b) Authentication and (c) Association (O'Hara, B. and Petrick, A.I, 2005). The Scanning phase is the dominating factor in handoff latency, accounting for more than 90% of the overall latency (Arunesh, M. et. al., 2003). The probing process (or scanning process) finds a new available AP with the best signal quality. Figure 3 illustrates the probing procedure as described in the IEEE Standard 802.11. In this figure, N distinct channels are selected to probe. Once the channels to be probed are determined, the MT switches to each selected channel.

4.2. MAC Frame Format

IEEE 802.11 MAC frame contains three fields:

- A MAC header, which comprises frame control, duration, address, and sequence control information.
- A variable length frame body, which contains information specific to the frame type.
- A frame check sequence (FCS), which contains an IEEE 32-bit cyclic redundancy code (CRC).

The frame control field is composed of:

-Protocol Version: The Protocol Version subfield is two bits in length. For 802.11 standards the value of the protocol version is 00.

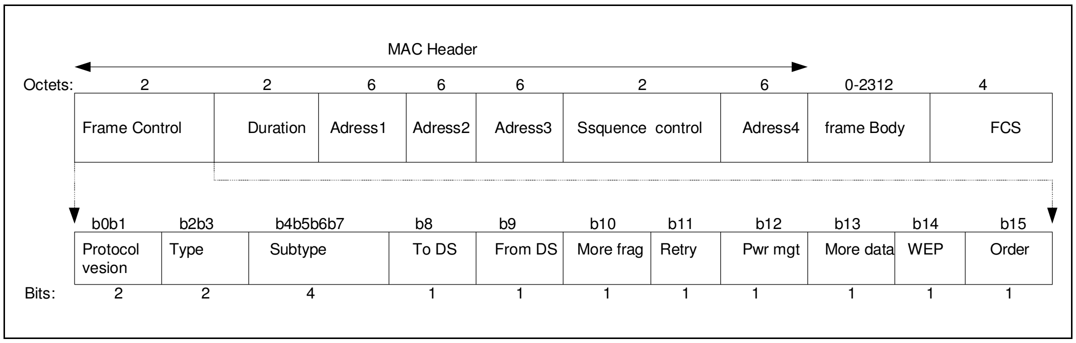


Figure. 4 Frame control field with MAC frame format

- **Type and Subtype**: The Type and Subtype fields together identify the frame function. There are three frame types: control, management and data frame. Each of the frame types has several defined subtypes. We present, in the table 2 only the screens of control and management frame, since the data frames are not discussed in this work.
- **To DS/From DS**: It is described in Table 1.

Table 1: To DS/From DS combinations in data type frames

To/From DS value	Meaning
To DS=0and From DS=0	A data frame moves from one STA to another STA within the same IBSS, as well as all management and control type frames
To DS=1 and From DS=0	Data frame destined for the DS
To DS=0 and From DS=1	Data frame exiting the DS
To DS=1 and From DS=1	The wireless distribution system(WDS) frame being distributed from one AP to another AP

Table 2: Valid type and subtype combination used in Handoff execution

Type value b_3b_2	Type description	Subtype value $b_7b_6b_5b_4$	Subtype description
00	Management	0000	Association Request
00	Management	0001	Association Response
00	Management	0010	Ressociation Request
00	Management	0011	Ressociation Response
00	Management	0100	Probe Request
00	Management	0101	Probe Response
00	Management	1000	Beacon
00	Management	1010	Disassociation
00	Management	1011	Authentication
00	Management	1100	Deautauthentication
01	Control	1011	RTS
01	Control	1100	CTS
01	Control	1101	ACK

- **More Fragments**: If the value is “1”, it means that there are still other fragments waiting for transmission.
- **Retry:** If the value is”1”, it means that the Data frame (or Management frame) is the retried frame.
- **Power Management**: A value of 1 indicates that the STA will be in a power-save mode. A value of 0 indicates that the STA will be in the active mode.
- **More Data**: The More Data field is set to 1 in broadcast/multicast frames transmitted by the AP, when additional broadcast/multicast MSDUs, or MMPDUs, remain to be transmitted by the AP during this beacon interval.
- **WEP**: It is set to 1 if the Frame Body field contains information that has been processed by the WEP algorithm.
- **Order**: It is set to 1 in any data type frame that contains an MSDU, or fragment thereof, which is being transferred using the Strictly Ordered service class.

5. HANDOFF PROCESS: DESIGN AND IMPLEMENTATION

In this section, we describe the implementation of handoff process. Five MAC components have been used in order to design the proposed circuit. Figure 5 illustrates Handoff system architecture divided into five parts. Those are controller module, receiver part, transmitter part, selection component and memory (256 words of 16 bits).

5.1. Building blocks specifications

5.1.1 Receiver Module

The receiver module receives MPDUs from PLCP (physical layer) and decodes packages. Table 3 lists MAC receiver part interface signals. The following notations are used to describe the signal type: I: Input signal; O: Output signal and I/O: Bi-directional Input / Output signal

Table 3: Receiver part interface signals

Name	Type	Description
CK	I:bit	Operation clock.
CN	I:bit	Sets receiver to receive data.
Recep_valiv	I:bit	Input from the controller module, it gives order to receive data.
Rts_recep	I:bit	Notifies transmitter that receiver got (RTS) frame.
Sig_level	I[15:0]	Input from the physical layer, it indicates the link quality with the corresponding AP.
In_recep	I[15:0]	Data from physical layer :(Probe Responses).
End_recep	O:bit	Notifies Controller that reception is complete.
Cts_recep	O:bit	Notifies that transmitter send Clear To Send (CTS) frame.
Write	O:bit	Output signal towards memory, it makes memory accessible in writing.
Out_recep	O:[15:0]	Output signal towards memory, to save all Probe response in the memory.
Adr_recep	O:[7:0]	Output signal towards memory, it selects the writing address.

5.1.2 Transmitter Frame Module

Transmit Frame Module is used as an interface to the physical layer that transmits frames. In this Transmit Frame Module, the frames are stored in buffer first, and then in order to be interfacied to Base-band module, used in physical layer. When transmission is completed, Transmit Frame Module will issue an "End_em" signal to inform the Controller Module that the transmission is finished. Table 4 gives more details about this component (input/ output signals).

Table 4: Transmitter part interface signals

Name	Type	Description
CK	I:bit	Operation clock.
CN	I:bit	Sets receiver to receive data.
Em_valiv	I:bit	Input from the controller module, it gives order to send data.
Cts_e	I:bit	The transmitter notifies that the corresponding AP is ready to receive data.
Sig_level	I[15:0]	Input from the physical layer, it indicates the link quality with the corresponding AP.
End_em	I:bit	Notifies Controller that the transmission is complete.
Rts_recep	O:bit	Notifies physical layer that the transmitter wants to send data.
Out_em	O:[15:0]	Data towards the physical layer :(Probe Request).

5.1.3. Control Module

All the actions are controlled or arranged by the Control Module in this design. The main function of the Control Module is to handle information or data from the physical layer and to coordinate all the other modules that include the receiver Module, the transmitter Module, selection component and the memory.

The probing process (or scanning process) finds a new available AP with the best signal quality. In this process, N distinct channels are selected to probe. Once the channels to be probed are determined, the Controller informs the transmitter to switch to the selected channel and broadcasts a probe request frame. After transmitting a probe request, APs respond with probe response frames to the MT and the controller must inform the receiver to accept data from the network, and it enables the memory to save data. This procedure is repeated until each selected channel to be probed.

At the end of the probing phase, (a probe requests from APs are stored in the memory). The controller activates the selection component to find the appropriate AP with the appropriate SNR and the suitable channel. Once the good AP and channel are found, the controller communicates again with the receiver and the transmitter in order to finish the authentication and the association phases.

Transmitter, receiver and control module provide the interface to external memory as a mailbox to exchange data. This memory has the capacity to store 256 words of 16 bits.

5.2. Handoff proposal: Model with reduced Scan phase

Using this model, the objective consists in reducing the handoff latency. We propose to alleviate the scan delay since it takes the major part of the handoff latency. In fact, this solution consists in transmitting the Probe requests on each scanning channels and stopping once a Probe response indication is received with an adequate SNR. An SNR threshold level has been defined to select an AP that provides a QoS guarantee. Figure 5 explains this approach based on reduced scan phase.

During the Scan phase based on the basis handoff model, the MT must sweep the total number (N) of the channels. The time allocated to scan each channel is called *MaxChannelTim.* Thus, the time of Scan is given by the following equation.

$$ScanTime = \text{Number of Channels}.\text{MaxchannelTime}$$

Where, MaxchannelTime is the time interval separating the first Probe Request and the last Probe Response on each channel.

The scan time can be reduced when minimizing the channel number to be scanned. By being unaware of negligible times, the idealized latency of this active Scan is given by the following relation

$$\text{ScanTime} = \sum_{c=1}^{c=\text{Num channel}} \big(1 - p(c)\big)\text{MinchannelTime} + p(c).\,\text{MaxchannelTime}$$

Where:

p(c) is the probability of one or more APs operating in the same channel (c), the Min Channel Time and the Max Channel Time values are respectively 1 ms an 11 ms. The ideal latency should extend from 11 ms to 110 ms. Taking the first equation account, it becomes unuseful to sweep all the channels while the most adequate AP belongs to an already scanned channel. In other terms, scanning the rest of the channels doesn't serve to find a useful AP, but it loses time which causes higher scan latency. The implementation of this model takes into account the specific threshold once reached, the MT stops the scan process and follows the rest of the basis handoff phases. Then, it is obviously that the reduced scan model, described in figure 5, leads to a fast communication establishment.

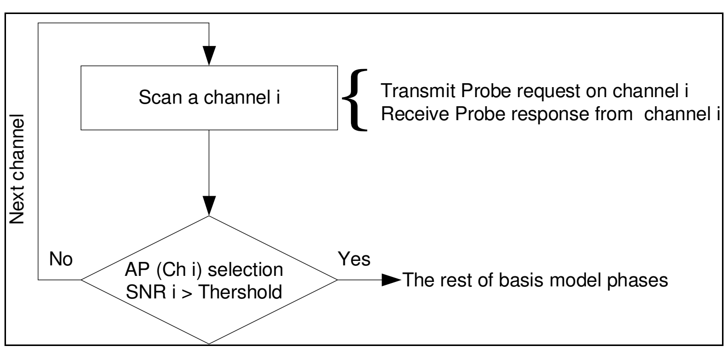


Figure.5 Handoff with a reduced Scan phase.

6. DESIGN RESULTS

6.1 Logic Synthesis

The designs were synthesized based on the 130 nm CMOS technology by using the Synopsys design_vision tool. We have written scripts that perform an automatic bottom-up synthesis of the design. The Synthesis results of the proposed circuits are presented in Table 5.

These results show that these circuits can operate with 1 GHz, which makes it more suitable for real time communications.

Table 5: Synthesis results.

	Basis Handoff		Handoff with reduced Scan: proposed		gain compared to Basis Handoff	
	Estimated area (mm2)	Estimated power (mW)	Estimated area (mm2)	Estimated power (mW)	Power gain (%)	Area gain (%)
500 MHz	0.114	22.8606	0.0917	18.2151	20.34	20.17
660 MHz	0.128	30.0922	0.0941	18.2972	39.20	26.56
1 GHz	0.133	46.1526	0.0986	18.3241	60.30	26.31

6.2 Clock Distribution: (Skew problem and clock times in the circuit)

The quality of the clock Distribution in a circuit plays a significant role in the performances of a synchronous circuit. The majority of numerical applications are implemented in synchronous logic, because the current tools for synthesis do not allow the automation for every design. These tools for synthesis allow the automation for design with combinational or sequential descriptions which rest on one or more clock. It is vital for a certain implementation that clock must be known and fixed in all the physical circuit, and its geometrical propagation does not imply distortion and dephasing. The solutions to guarantee a uniform clock distribution without skew dephasing are multiple. The best solution used today to reduce the clock dephasing is based on the concept of clock tree, it inserts on each level of hierarchy, buffer or reverser which rectifies the clock signal skew locally. This solution has the advantage of producing a geographically distributed and optimized consumption.

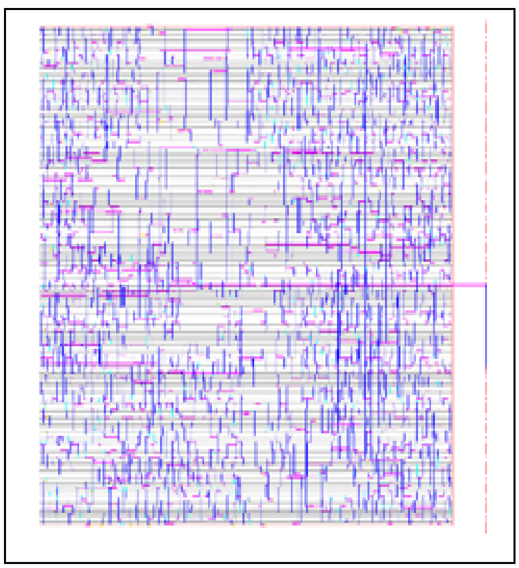
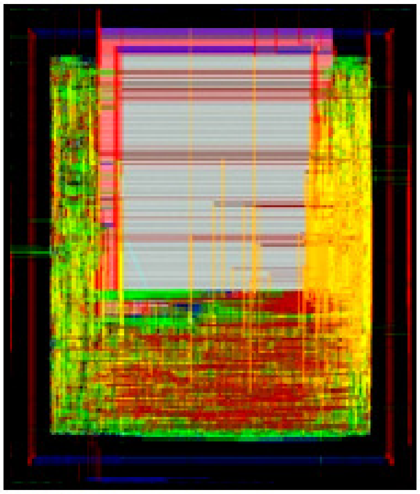


Figure. 6 Clock tree in silicon level

6.3. Layouts

Complete layout designs of the chips are performed by using the Cadence tools (Encounter) at the frequency of 1 GHz. We have used the one-block approach in order to meet the timing requirements and to generate the clock tree efficiently. The chip of basis handoff a circuit contains 77 signal pins in total, 0.0567 mm^2 for Combinational area and 0.073 mm^2 for No combinational area. While, handoff with reduced scan contains 77 signal pins in total, 0.0314 mm^2 for Combinational area and 0.0672 mm^2 for No combinational area.



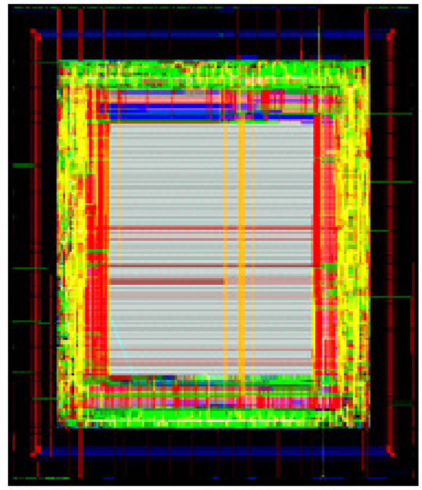


Figure.7 a: layout of the basis Handoff b: layout of the modified Handoff

The IEEE 802.11b Standard proposes a theoretical flow of 11 Mbps (5 to 7 Mbps in real case according to the environment), thus, an average of 6 Mbps. In a free space environment, the frequency band is the 2.4 GHz with three available radio channels. Moreover, 802.11b proposes a MinChannelTime, equal to 670 µs, DIFS equal to 50 µs and SIFS equal to 10 µs. Using these technological parameters and the values of frequencies obtained in table 8, our circuits reduce the handoff time for each model as outlined in table 9. As a result, the average of the handoff latency is maintained between 0.74 and 2.22 ms for the reduced scan model. Both schemes in (Shin, M. et. al., 2004) and (Vladimir, B. et. al., 2005) attempt to reduce the time spent in the channel scanning phase when a handoff occurs. By changing the APs and the clients, and by increasing coordination between them, Neighbor Graphs achieve a handoff latency of about 40 ms, and SyncScan handoffs take 2-3 ms. But, the technique requires periodic suspension of communication that could last more than 10 ms, depending on the given hardware. Table 6 provides more details allowing a simple comparison of the different handoff mechanisms cited in this paper.

Table 6: Comparison of different handoff mechanisms

	Wireless interface	**Handoff latency (ms)**	**Infrastructure modification**
Neighbor Graphs (Shin. M et. al., 2004)	1	~ 40	yes
SyncScan (Ramani,I. and, and Savage, S., (2005)	1	2 – 3	yes
MultiScan (Vladimir B, et. al., 2005)	2	0	no
Basis Handoff (hardware)	1	~ 2.2	no
Reduced scan model (Hardware)	1	0.74 – 2.22	no

In the following scenario, an MT must sweep three channels. On each channel, three APs are active. The Handoff latency, according to the number of APs and the channels, is then as follows:

First, a TM performs the scan of three channels. On each channel, it expects to receive three answers from three APs. The signal level detected during the reception will be recorded. After consulting the first channel, the TM changes its frequency and sends probe request on the next channel to collect the parameters characterizing the access point communicating on the same frequency (channel 2). This scenario is repeated for all channels to scan.

With reduced scan, the objective consists in reducing the time scan phase. So a TM stops the scan since it detects a suitable signal with a guarantee of the QoS parameters.

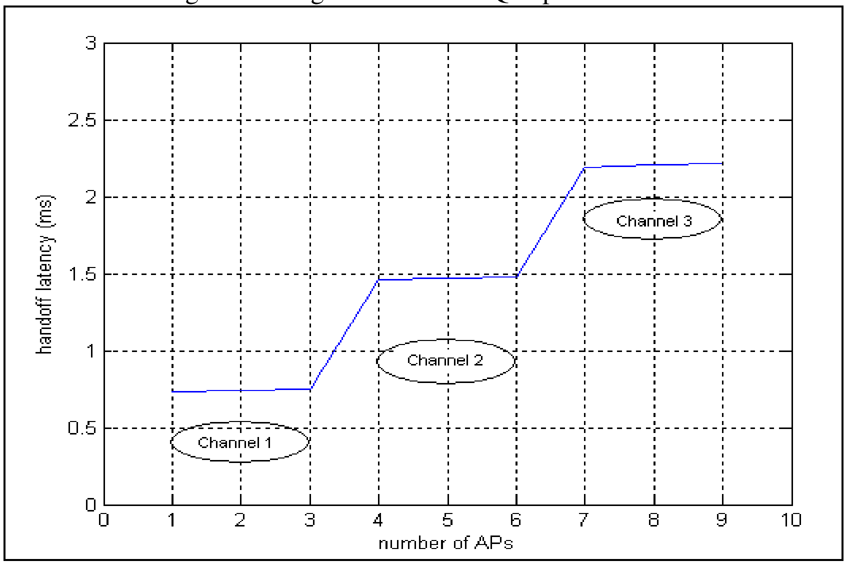


Figure.8 Handoff latency vs. Channels and APs number

If the adequate signal level is received in the first channel or in the second channel; the scan time can be reduced to 1 / 3 or 2 / 3 respectively.

7. CONCLUSION

In this paper, the IEEE 802.11 convectional handoff process has been implemented on an ASIC circuit using the high level design technique and based on the IEEE 802.11b specifications. The conventional layer-2 handoff consumes more time in the channel-scanning process. For this reason, we have proposed an other handoff mechanism, using a reduced scan phase. Several scenarios have been employed in order to evaluate the handoff latencies spent for each model compared with others mechanisms for the conventional layer-2 handoff process. Reducing handoff latency in WLAN becoming more suitable for real time applications. For this reason we adopt the high level design for the implementation of these models. In fact, we have used VHDL as a high level description language, ModelSim as a simulation tool to check the behavior of each model at the RTL level. Synopsys and cadence tools are used for synthesis, place and route step respectively.

Other interactions between the 802.11 MAC layer and IP protocols need further study. Since 802.11 will be the dominant technology for WLANs, a fresh look at integrating the IP stack and the wireless MAC must be justified to design a SOC (System on Chip) of IEEE 802.11 MAC layer.

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