A Performance Study of Roaming in Wireless Local Area Networks Based on IEEE 802.11r

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***Abstract*—The wide deployment of IEEE 802.11 based wireless local area networks (WLANs), and increased interest in multimedia applications support in WLANs, have lead to the need to support real-time applications even when devices are roaming across WLAN access points (APs). This has lead to the development of the IEEE 802.11r fast roaming mechanism, in which a connection to a candidate AP is established before the loss of connectivity with the current one. In this paper, we study the performance of the IEEE 802.11r and its viability for real-time applications. Our simulation results demonstrate the flexibility of the IEEE 802.11r and the effectiveness of its roaming procedure. Also, a noticeable reduction in roaming time and delays at APs is shown to be achievable, which guarantees the required quality of service level of Voice over IP over WLAN (VoWLAN) applications.**

Index Terms*—*Fast Basic Service Set Transition, Roaming.

I. Introduction

The interest in supporting real time applications, such as Voice over IP, over cost effective wireless LAN (WLAN), has dramatically increased in the last decade. Since the classical 802.11 WLAN standard does not support differentiated services, traffic is equally treated as best effort traffic. This makes it unable to support delay sensitive applications because of their Quality of Service (QoS) requirements [1]

The enhancement of WLANs to support QoS result to increased the number of exchanged messages between stations (STAs) and access points (APs). As consequence, roaming time is increased to unacceptable levels. Therefore, some concepts in the current design of WLAN need to be reformed to accommodate such applications. Currently, roaming time between different APs is one of the most important issues to be tackled in WLANs. In fast roaming, mobile STAs seamlessly disassociate and associate from one AP to another without loss of connectivity as presented in Figure 1. For this process to be achieved, the deployment of such APs needs to be overlapped in coverage at the borders which gives a mobile STA the ability to receive acceptable signal strength from another AP while it is still connected with its current one [2].

The IEEE Task Group (TGr) was formed to address the roaming time issue. IEEE 802.11r protocol provide a mobile STA with several features such as the ability to request Quality of Service (QoS) resources during re-association phase, hence avoiding sending a separate message to reserve resources before data transfer can be done. This saving of time can help to achieve a good voice quality during transition periods. Also, using IEEE 802.11r, a mobile STA can benefit from making a reservation prior to performing the transition using Traffic Specification (TSPEC) element if an AP appears to be heavily loaded and the mobile STA requirements can not be meet by the available admission capacity. In such a case, the QoS reservation done while the mobile STA is still connected to the current AP can help to avoid failed re-association attempts [3] [4].

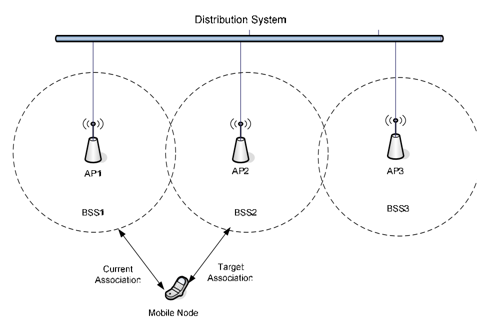

Fig. 1. *Roaming in WLAN overview*

However, before the IEEE 802.11r can become widely available, extensive performance evaluation studies are needed. The result of this paper is an evaluation of Fast Basic Service Set (BSS) Transition standard, IEEE 802.11r, which attempts to eliminate BSS transition time while still providing the services offered by IEEE 802.11e.

The remainder of the paper is organized as follows: Section II presents an overview of QoS in IEEE 802.11e. Roaming in classical IEEE 802.11 is discussed in section III. Section IV comprises a detailed description of the roaming procedure using IEEE 802.11r. Section V presents a performance evaluation of IEEE 802.11r protocol including the system model, simulation assumptions and parameters as well as the simulation results. Section VI concludes the paper and gives possible directions for future work.

II. Quality of Service in IEEE 802.11e

Due to the deployment simplicity and the cost effectiveness of WLANs, currently much research has been done to provide differentiated services support. The IEEE 802.11e has been standardized to enhance the IEEE 802.11 networks to be able to provide multi class traffic support ranging from real-time traffic such as voice and video to background traffic such as FTP and Email services. These extensions are defined to meet the QoS levels required by different services [1] [2].

In order to support the above mentioned applications, the IEEE task group E has introduced mechanisms to support differentiated services over WLAN. A new function called Hybrid Coordination Function (HCF) was included in the 802.11e standard. This function comprises two medium access mechanisms: contention-based channel access and controlled channel access. Contention-based channel access is referred to as Enhanced Distributed Channel Access (EDCA), and controlled channel access is referred to as HCF Controlled Channel Access (HCCA). In EDCA, different priority access levels have been classified which known as Access Categories (ACs). There are four different ACs in each STA which correspond to four traffic classes. The four access categories are labeled as (VO) for Voice, (VI) for Video, (BE) for Best Effort and (BG) for Background traffic. The 802.11e standard determines Traffic Specification (TSPEC) elements to be used for admission control in HCF. These TSPECs are used by the STA to inform the AP about its QoS requirements. The AP might accept or reject TSPEC based on the traffic conditions [2] [5] [6] [7] .

III. ROAMING IN IEEE 802.11

The IEEE 802.11 has to accommodate security and QoS support. The security issue in WLAN was solved using IEEE 802.11i amendment which introduces robust authentication, data integrity and encryption mechanisms. Also, IEEE 802.11e standard aims to provide QoS support to real-time applications. Such support can be performed by providing each STA with four access categories. However, this increases the management frames exchanged between the STAs and APs, especially during transition process. As each STA performs roaming from one AP to next, it should perform several steps as illustrated in Figure 2.

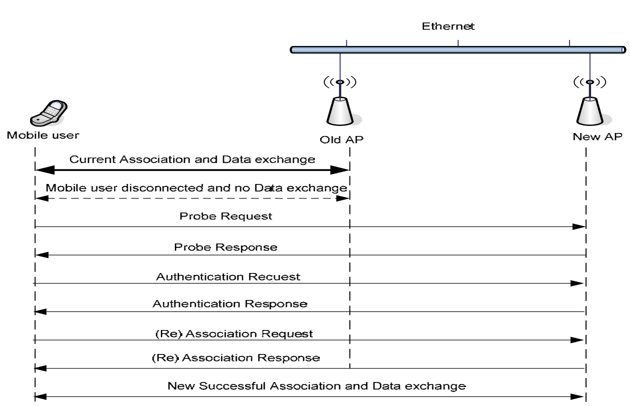

Fig. 2. *Roaming Process without IEEE 802.11r*

These steps might take up to several hundred milliseconds. Such high delay can degrade a mobile STA experience running a real-time application over WLAN. For instance, real time applications are delay sensitive hence the voice connection might be dropped while waiting for the full re-authentication to be finished. In addition, extra overheads will be added because of the required TSPECs renegotiation with the new AP [1] [7]. In order to minimize the delay associated with STA roaming to another AP, the authentication server and the mobile STA would agree upon one set of Pairwise Master Keys (PMK). The STA and AP can use PMK to store the results of the first contact 802.1X authentication, so only four-way handshake is needed when such STA roams back to the same AP. The STA might optionally use pre-authentication to perform 802.1X authentications with another AP in its area while still connected with the current AP. Such mechanisms do not perform well especially when real-time applications are present in the network. These mechanisms do not get enough attention in terms of implementation and deployment because they are optional. This brings up a need for a new mechanism by which the mobile STA can scan the area for available APs to build an AP database and select the one which provide best signal. In such mechanism the re-authentication, reauthorization and QoS renegotiation periods during roaming process could be minimized to provide mobile terminals with a good experience.

IV. ROAMING USING IEEE 802.11r

Recently, a TGr group (802.11r) was established to come up with solutions to minimize the time required for Basic Service Set (BSS) transition process to support real-time applications. The main goal of the new mechanism is to make the target AP ready for next roaming before the STA starts roaming. The AP database plays an essential role towards achieving this goal.

The current draft recommends generating the PMK once the mobile STA joins the network. All APs that are authenticated in the same subset should get the PMK. Hence, When the STA roams between APs, the PMK will be present, this procedure reduces the overhead in the system and also minimize the latency resulted when mobile STAs connected to the back end system. Both the four-way handshake and the IEEE 802.11e TSPECs must be performed before the mobile STA starts the roaming process. Based on the last draft, in order to further reduce the transition time the four-way handshake and the resource reservation are added into the re-association process as presented in Figure 3. While a STA in classical 802.11 needs to perform the full authentication during re-association phase [3]. The following describes the 802.11r procedure to reduce latencies during BSS transition.

1) ***Handshake procedure:*** IEEE 802.11r minimizes the number of steps required for handshake as presented in Figure 3. The roaming latency is reduced by merging the key management and QoS resource allocation with the 802.11 reassociation process. The new handshake process introduces a number of new information elements. One of these elements is the Resource Information Container Information-Element

(RIC-IE). The mobile STA uses a RIC-IE to send its preferred QoS requirements to the AP. In a response message, the RIC-IE contains the QoS resources the AP has allocated to the mobile STA, or suggests alternate level of QoS the AP can support [3].

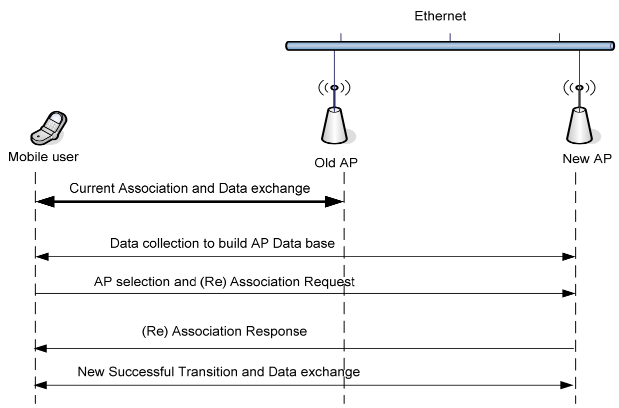

Fig. 3. *Fast Roaming Process with IEEE 802.11r Protocol*

*2) **Resource Reservation**:* When the scan phase is over and the database shows there are lightly loaded APs nearby, the mobile STA can choose one as a target AP for next roaming. On the other hand, if the database shows that no nearby AP is lightly loaded, however, making a transition is a wrong decision and might result in dropping the call.
IEEE 802.11r introduce two different resource reservation schemes to overcome this problem, namely, the Over-the-Distribution System (DS) scheme and the Over-the-air scheme. The Over-the-DS scheme based on the fact that the mobile STA has a pre-existing association with its current AP. In such a case the mobile STA executes the resource reservation transition with the target AP via the physical link it has with the current AP. The current AP forward messages between target AP and the mobile STA. The advantages of this scheme are, the mobile STA will not go off-channel to complete the exchange, and also the current AP can limit the number of allocated resources the mobile STA makes.

The Over-the-air scheme added an extra round trip to the transition process. The new transaction method takes advantage of the information elements used in the reassociation exchange of the handshake, the AP commit resources before the mobile STA is accepted at the new AP. This scheme uses two mechanisms to limit mobile STA rejection. First, the mobile STA can allocate resources only with a small number of APs in the 802.11 radio range. Second, the AP aggressively time out unused reserved resources. The disadvantages of this scheme such as the mobile STAs must be off-channel for the first few messages, which result in dropping some data sent by current AP. Moreover, it is hard to deal with the real-time schedular on resource constrained mobile STA [3].

V. PERFORMANCE EVALUATION

In order to evaluate the effectiveness of the new roaming protocol (IEEE 802.11r) in terms of minimizing the roaming time between APs in the same Extended Service Set (ESS) while providing mobile STAs with acceptable QoS levels, a set of simulation experiments were conducted. The following subsections outline the simulation model, obtained results and their analysis.

A. Simulation Model

Our simulation model was performed to study the performance of the new Fast Basic Service Set Transition (IEEE 802.11r) protocol with the support of QoS mechanism IEEE 802.11e. The VoIP over WLAN application is used to emulate real-time traffic. The infrastructure mode was applied by arranging a number of mobile and stationary STAs within APs, which form a wireless connection between all IEEE 802.11e STAs in the wireless domain and the wired STAs (APs) in the wired domain. The simulation setting used is shown in Figure 4.

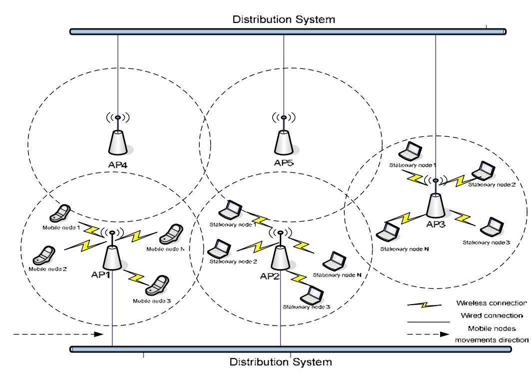

Fig. 4. *Network Topology*

Stationary STAs act as traffic loading STAs and they do not go further than their AP coverage area (AP_2 and AP_3). The APs labelled (AP_1, AP_2, AP_3, AP_4, AP_5) are connected to the wired network as shown in Figure 4, using high capacity links with negligible delay and thus no loss occurrs on these links. The APs use First In-First Out "FIFO" queuing to serve packets that received from different STAs. To avoid interference the APs were configured to operate on different non-overlapping channels. These APs are designed to support IEEE802.11r features. The STAs of interest are the mobile STAs, which are the roaming wireless STAs. These STAs first associated with AP_1, but as they move and go beyond their AP coverage area, they will re-associate with the best AP in the area and then disassociate from their current AP. All STAs in the same AP coverage area are placed within the range of each other to avoid the hidden and exposed node problems. This help STAs to use the maximum data rate for sending their traffic.

B. Simulation Assumptions

We make the following assumptions:
1) There is no loss in the links between APs and the distribution system.
2) All mobile STAs are pre-authenticated with all APs in the same ESS.
3) The first factor used to evaluate each AP is the signal strength and the second is the load conditions.

C. Simulation Parameters

The parameters used for the simulation are listed in TableI.

TABLE I
SIMULATION PARAMETERS

Parameter	Value
Access Points	5
Mobile Stations	20
Stationary Stations	16
Transmission Rate	54 Mbits/sec
Transmit Power(W)	0.002
Buffer Size	50 packets
Traffic Type	Voice (CBR)

In our simulation each STA generates VoIP traffic as Constant Bit Rate (CBR) traffic. The parameters of these sources were setup to model G.711 voice traffic at 64 bits/sec with 20 ms payload. This scheme has been chosen because it is commonly used and is relatively simpler than other schemes. As in [8], the data payload size of the VoIP is 160 bytes generated every 20 ms where the 20 byte IP header, the 12 byte RTP header and the 8 byte UDP header were added. To avoid problems with traffic synchronization, a low level of random noise was introduced into the packet generation procedure, which results in each source generating a 200 byte packet each 20 milliseconds [4] [8]. The performance metrics selected for results comparison are roaming time which is the time a user spends to switch its connection from current AP to a target AP, average packet loss which represents the average number of unsuccessfully delivered packets, and AP queue size which show the number of STAs associated with each AP.

D. Simulation Results

In our simulation scenario, the mobile STAs move to the right direction following their trajectories using the features of IEEE 802.11r to evaluate the available APs in the surrounding area to select best ones for next roaming. When the mobile STAs move away from their APs, the signal provided by their current APs becomes weaker, such situation triggers the mobile STAs to start the evaluation process by sensing the signals from other APs in the surrounding area. The evaluation process helps each STA to collect important information about the possible APs and build AP database. However, the most important information which the mobile STA will use to select the best AP is the signal strength and the load conditions in each BSS.
Roaming time is a very important performance metric for delay sensitive applications such as voice and video traffic. It is essential to maintain a high voice quality during the transition process. It has been shown using simulation that roaming times, and therefore voice quality, are better when IEEE 802.11r is implemented.

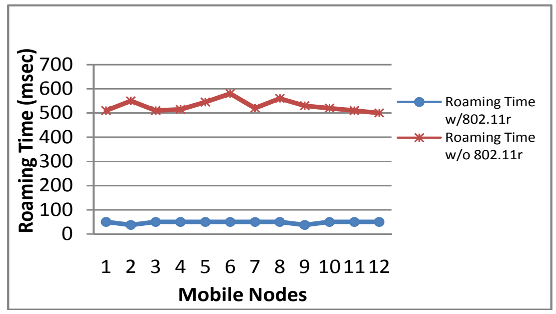

Fig. 5. *Roaming Time Comparison*

The simulation results depicted in Figure 5 show that IEEE 802.11r has a significantly lower roaming time compared to the classical IEEE 802.11. It can be noted that this reduction in roaming time results in fewer packet loss and hence STAs can experience higher QoS levels.
Figure 6, shows that the IEEE 802.11r also has significantly lower packet loss compared to classical IEEE 802.11. This is due to the small period of time a STA takes for reconnection process, where fewer packets are actually dropped. It is clearly noted that the dropping of packets has more to do with roaming time than voice call re-connection time. Thus, IEEE 802.11r performs better in terms of packet loss and provides real-time applications with acceptable QoS level.
AP queue size is one of the most important performance factors and provides an indication on current load conditions of each AP.

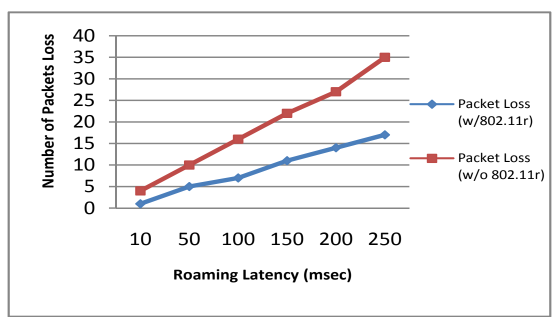

Fig. 6. *Packet Loss Comparison*

Figure 7 shows the sizes of the APs queues when IEEE802.11r is supported. Apparently, about 20% of the queue size of AP_1 was filled with mobile STAs traffic. In addition, as mobile STAs start to move out of AP_1 coverage, the evaluation procedure starts, and the mobile STAs find that the stronger signal is from AP_5.

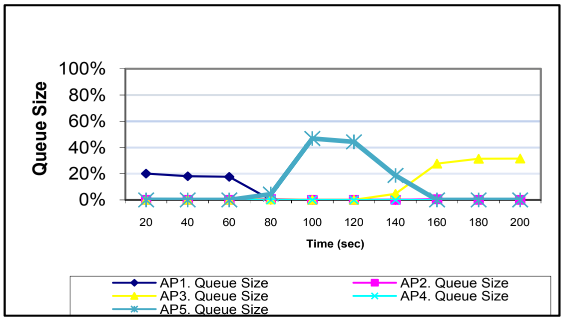

Fig. 7. *AP Queue Size (with IEEE 802.11r)*

Hence STAs start to roam to BSS_5 as can be observed by checking its queue size. Therefore, AP_5 queue size increases until it reaches 50%. Furthermore, as the mobile STAs continue to move, they start to look for another AP. At this time, AP_2 and AP_3 can provide stronger signal. Thus, mobile STAs choose to roam to AP_3 because it was closer and provides better offers in terms of load and signal strength. It is clear that IEEE 802.11r makes mobile STAs able to choose best AP in terms of signal strength and load conditions in each BSS.
Figure 8 shows that initially the mobile STAs are connected to AP_1. This makes the queue size occupancy of AP_1 about 20%. As the mobile STAs start to move to the right direction, they start searching for new APs. The first signal heard by these STAs comes from AP_2 thus the STAs start to switch to this AP without any concern about the load conditions. As depicted in Figure 8, the AP_2 queue size starts to increase until it reaches 98%, while other APs are lightly loaded and can provide acceptable signal, therefore their queues remain empty. The mobile STAs switch from AP_2 to AP_3 because AP_3 was the closest one to provide better signal. In the classical IEEE 802.11 networks, however, mobile STAs do not have the ability to evaluate APs in the area and choose the one which offer best services.

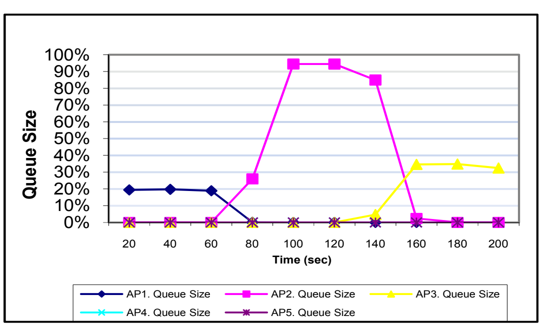

Fig. 8. *AP Queue Size (without IEEE 802.11r)*

VI. CONCLUSION

Fast transition from one AP to another is an important feature in WLAN. It is significantly important to achieve fast roaming in order to provide an acceptable voice quality. This paper has addressed the problem that exists as a result of the 802.11 standard enhancements. Our results show that IEEE 802.11r has the ability not only to support 802.11e features, but also to reduce the transition time between available APs, and hence to allow high quality voice calls while a STA performs a transition from one AP to another. This improvement would make WLAN receive more attention and provide customers with appropriate services. Moreover, minimizing the roaming time helps to reduce packet loss rate which allow more voice packets to be delivered without being dropped.
A combination of IEEE 802.11r protocol with other proposals such as IEEE 802.11k for Radio Resource Measurement and the already exist IEEE 802.11e protocol for QoS support will be a good enhancement for managing the limited resources in WLANs.

REFERENCES

[1] IEEE Std 802.11, IEEE Standard for Wireless LAN Medium Access Control (MAC) and Physical Layer Specifications (With Amendment 1 - 4), 2003.
[2] IEEE Std 802.11e Draft 13, IEEE Standard for "Wireless LAN Medium Access Control (MAC) and Physical Layer Specifications (Amendment: Quality of Service (QoS) Enhancement)", 2005.
[3] IEEE Std 802.11r /D01.0, Draft Amendment to Standard for Information Technology - Telecommunications and Information Exchange Between Systems - LAN/MAN Specific Requirements - Part 11: Wireless Medium Access Control (MAC) and Physical Layer Specifications: Amendment 8: Fast BSS Transition, 2005.
[4] C. Yap, "Issues with real-time streaming applications roaming in QoS-based secure IEEE 802.11 WLANs," in Proceeding of the 2nd international conference on Mobile Technology, Applications and systems, 2005.
[5] A. Kospel, J.P. Ebert and A. Wolisz, A performance comparison of point and distributed coordination function of an IEEE 802.11 WLAN in the presence of real-time requirements, in: 7th International Workshop on Mobile Multimedia Communication (MoMuC2000) October, 2000.
[6] M. Stefan, C. Sunghyun, M. Peter,K. Ole, H. Guido and S. Lother, "IEEE 802.11e Wireless LAN for Quality of Service," in Proceedings of European Wireless, Feb.,2002.
[7] IEEE Std 802.11i, IEEE Standard for Wireless LAN Medium Access Control (MAC) and Physical Layer Specifications (Amendment 6: Medium Access Control Security Enhancements), 2004.
[8] J. Yu, S. Choi, and J. Lee, "Enhancement of VoIP over IEEE 802.11 WLAN via Dual Queue Strategy," In Proc. of the International Conference on Communications (ICC '04), Paris, France, June, 2004.