Seamless Continuity of Real-Time Video across UMTS and WLAN Networks: Challenges and Performance Evaluation

Apostolis K. Salkintzis[1], Gerasimos Dimitriadis[2], Dimitris Skyrianoglou[3], Nikos Passas[3] and Niovi Pavlidou[2]

[1]Motorola [2]Aristotle University of Thessaloniki Greece [3]University of Athens Greece

Accepted for publication in: IEEE Wireless Communications
Special issue on "Toward Seamless Interworking of Wireless LAN and Cellular Networks"

Corresponding author: Apostolis K. Salkintzis
Motorola
salki@motorola.com
Tel: +30-210-8172335
Fax: +30-210-6810168

Abstract

This article addresses several challenges related to the evolution towards seamless interworking of wireless LAN and 3G cellular networks. The main objective is to evaluate the conditions and restrictions under which seamless continuity of video sessions across the two networks is feasible. For this purpose, we formulate a number of practical interworking scenarios, where UMTS subscribers with ongoing real-time video sessions handover to WLAN, and we study the feasibility of seamless continuity by means of simulation. We particularly quantify the maximum number of UMTS subscribers that can be admitted to the WLAN, subject to maintaining the same level of UMTS QoS and respecting the WLAN policies. Our results indicate that the WLAN can support seamless continuity of video sessions for only a limited number of UMTS subscribers, which depends on the applied WLAN policy, access parameters and QoS requirements. In addition to this study, we do address several other issues that are equally important to seamless session continuity such as, the QoS discrepancies across UMTS and WLAN, the vertical handover details, and various means for access control and differentiation between regular WLAN data users and UMTS subscribers. The framework for discussing these issues is created by considering a practical UMTS/WLAN interworking architecture.

1. Introduction

The interworking between 3G cellular and Wireless Local Area Networks (WLANs) has been considered as a suitable and viable evolution path towards the next generation of wireless networks. Yet, this interworking raises considerable challenges, especially when we demand for seamless continuity of multimedia sessions across the two networks. To deal with these challenges several 3G/WLAN interworking requirements need to be identified and fulfilled.

Typically, the 3G/WLAN interworking requirements are specified and categorized in terms of several usage scenarios [1, 2]. For example, a common usage scenario is when a 3G subscriber is admitted to a WLAN environment by re-using his regular 3G credentials, and then obtains an IP connectivity service (e.g., access to the Internet). In this case, the interworking requirements include support of 3G-based access control, signaling between the WLAN and the 3G network for Authentication, Authorization and Accounting (AAA) purposes, etc. Other scenarios can call for more demanding interworking requirements. We may envision, for instance, a scenario in which a 3G subscriber initiates a video session in his home 3G network and subsequently transits to a WLAN environment, wherein the video session is continued *seamlessly*, i.e., without any noticeable change to the quality of service (QoS). In this case, not only 3G-based access control is required, but also access to 3G-based services is needed over the WLAN network, which in turn calls for appropriate routing enforcement mechanisms. More importantly, however, there is need for QoS consistency across 3G and WLAN, which appears to be not very straightforward given the different QoS features offered by these networks. Indeed, WLANs have initially been specified without paying much attention to QoS aspects and aiming primarily to simple and cost-effective designs. Even with the recent IEEE 802.11e [8] developments, WLAN QoS still exhibits several deficiencies with respect to the 3G QoS (this is further discussed later on). On the contrary, 3G cellular networks were built with the multimedia applications in mind and trade simplicity and cost for inherently providing enhanced QoS in wide-area environments.

Our main interest in this article is to examine the challenges of seamless session continuity across UMTS and WLAN, and also to evaluate the conditions and restrictions under which seamless continuity is feasible. For this purpose, we formulate a number of practical interworking scenarios, where UMTS subscribers with ongoing real-time video sessions handover to WLAN, and we consider the capability of WLAN to provide seamless session continuity under several policy rules and WLAN traffic loads. One measure we are particularly interested to quantify is the maximum number of UMTS subscribers[1] that can be admitted to the WLAN, subject to maintaining the level of UMTS QoS and respecting the WLAN policies. Although our study focuses primarily of QoS consistency, we do address several other issues that are equally important for enabling seamless session continuity such as, routing enforcement, access control and differentiation between the traffic of regular WLAN data users and UMTS roamers. The framework for discussing these issues is created by considering a practical UMTS/WLAN interworking architecture, which conforms to the 3GPP specifications [2, 3] and other interworking proposals found in the technical literature (e.g., [1]).

[1] The UMTS subscribers admitted to the WLAN are also referred to as *UMTS roamers*.

2. UMTS/WLAN Interworking Architecture

The end-to-end interworking architecture we are considering is illustrated in Fig. 1 and it is compliant with the proposals in [1] and [2]. Below we briefly discuss the main characteristics of this architecture. Note that our goal is not to provide a comprehensive description but rather to set the ground for the next sections and define the real-life environment that our study applies to. This creates the right context for the subsequent discussion and makes it easy to assess the importance of the provided results. For more detailed information on the considered architecture the interested reader is referred to [1-5].

Fig. 1: The considered end-to-end interworking architecture for seamless multimedia session continuity.

As shown in Fig. 1, the 3G network supports access to a variety of IP multimedia services via two radio access technologies: UMTS Terrestrial Radio Access (UTRA) and WLAN access. Access control and traffic routing for 3G subscribers in UTRA is entirely handled by the UMTS Packet-Switched (PS) network elements, which encompass the Serving GPRS Support Node (SGSN) and the Gateway GPRS Support Node (GGSN) (see [4] for more details). On the other hand, access control and traffic routing for 3G subscribers in WLAN (*UMTS roamers*) is shared among the WLAN and the UMTS network elements as discussed below. The important assumption we make, as shown in Fig. 1, is that 3G subscribers can change radio access technology and keep using their ongoing multimedia sessions in a seamless fashion. Thus, we assume that *seamless service continuity* is provided. This assumption raises considerable challenges and, as noted above, we are interested to investigate the capability of WLAN to support this seamless service continuity under specific scenarios.

The WLAN access network may be owned either by the UMTS operator or by any other party (e.g., a public WLAN operator, or an airport authority), in which case the interworking is enabled and governed by appropriate business and roaming agreements. As shown in Fig. 1, in a typical deployment scenario the WLAN network supports various user classes, e.g., UMTS roamers and regular WLAN data users (i.e., no 3G subscribers). Differentiation between these user classes and enforcement of corresponding policies is typically enabled by employing several Service Set Identifiers (SSIDs). For example, the regular WLAN data users may associate with the SSID that is periodically broadcast by the Access Point (AP), whereas the UMTS roamers may associate with another SSID that is also configured in the AP, but not broadcast (see [5] about the usage of SSIDs). In this case, the WLAN can apply distinct access control and routing policies for the two user classes and can forward the traffic of WLAN data users e.g. to the Internet and the traffic of UMTS roamers to the UMTS PS core network (as shown in Fig. 1). Such routing enforcement is vital for supporting seamless service continuity and can be implemented as discussed in [1]. Moreover, different AAA mechanisms could be used for the different user classes.

For enabling interworking with WLANs, the UMTS PS core network incorporates three new functional elements: the *3G AAA Server*, the *WLAN Access Gateway* (WAG), and the *Packet Data Gateway* (PDG). The WLAN need also support similar interworking functionality to meet the access control and routing enforcement requirements. The 3G AAA Server in the UMTS domain terminates all AAA signaling originated in the WLAN that pertains to UMTS roamers. This signaling is securely transferred across the *Wr/Wb* interface, which is typically based on *Radius* [6] or *Diameter* [7] protocols. The 3G AAA Server interfaces with other 3G components, such as the WAG, the PDG and Home Subscriber Server (HSS), which stores information defining the subscription profiles of 3G subscribers. The 3G AAA Server can also route AAA signaling to/from another 3G networks, in which case it serves as a proxy and it is referred to as *3G AAA Proxy* (see [1]).

As shown in Fig. 1, traffic from UMTS roamers is routed to the WAG across the *Wn* interface and finally to the PDG across the *Wp* interface. This routing is enforced by establishing appropriate traffic tunnels after a successful access control procedure. The PDG functions much like a GGSN in a UMTS PS core network. It routes the user data traffic between the MS and an external *Packet Data Network* (PDN) (in our case, the IP Multimedia Network) and serves as an anchor point that hides the mobility of the MS within the WLAN domain. The WAG functions mainly as a route policy element, i.e., ensure that user data traffic from authorized MSs is routed to the appropriate PDGs, located either in the same or in a foreign UMTS network.

Although Fig. 1 shows the architecture that can support seamless session continuity, it does not address the dynamics of handover procedure, which is especially important for the provision of seamless continuity. To further elaborate on this key procedure, we depict in Fig. 2 a typical signaling diagram that pertains to a situation where a mobile station (MS) hands over from UMTS to WLAN in the middle of an ongoing packet-switched video session. The establishment of the video session is triggered at instant *A* and in response the MS starts the Packet Data Protocol (PDP) context establishment procedure for requesting the appropriate QoS resources (described by the "Req. QoS" Information Element (IE), see [16]). The UMTS network acknowledges the request and indicates the negotiated QoS resources (specified by the "Neg. QoS" IE) that could be provided. After that, video traffic on the user plane commences and the video session gets in progress. At some point the MS enters a WLAN coverage area and it starts receiving Beacons[2] from the nearby Access Points (APs). We assume that this can happen concurrently with the ongoing video session because, although the MS has one transceiver available, can periodically decode signals on other frequency channels for inter-system handover purposes. The MS may need to check if the detected WLAN supports one of its preferred *Service Set Identifiers* (SSIDs) before considering it valid for inter-system change. For this purpose, the MS *probes* for a preferred SSID, denoted as SSID(g), according to the applicable procedures in [5].

Fig. 2: Typical signalling during handover of a video session from UMTS to WLAN (HCCA availability is assumed).

At instant *C* the MS takes the decision to handover to the detected WLAN and thus suspends the ongoing video session. This may demand further signaling with the UMTS but we skip it for simplicity. After switching to the WLAN channel, the normal 802.11 authentication and association procedures [5] are carried out. Subsequently, the UMTS-based access control procedure is executed in which the MS is authenticated and authorized by means of its regular 3G credentials (see [1, 2] for more details). At this stage, a tunnel will also be established for routing further MS traffic to a UMTS entry point (the WAG according to Fig. 1). Next, the MS uses 802.11e QoS signaling (assuming it is supported by the WLAN) to reserve the appropriate resources for its suspended video session. The Traffic Specification (TSPEC) element carries a specification of the requested QoS resources. For the objectives of seamless continuity, it is apparently that TSPEC needs to be set consistently with the QoS negotiated in the UMTS system. After this point, the video session is finally resumed in the

[2] From the Beacons the MS discovers what particular QoS features the WLAN supports, if any.

WLAN, possibly after some high-layer mobility management procedures (e.g., Mobile IP or SIP).

From the above discussion it becomes evident that vertical handovers from UMTS to WLAN (and vice versa) present several challenges, especially for minimizing the associated latencies and the interruption of ongoing multimedia sessions. Apart from that however, the maintenance of consistent QoS across the UMTS and WLAN networks is equally challenging and is the focus of our subsequent discussion.

3. Interworking QoS Considerations

One vital component for the provision of seamless multimedia session continuity is the *QoS consistency* across the WLAN and UMTS networks. This is vital indeed because without QoS consistency the multimedia sessions will experience different QoS levels in the two network domains and hence seamless continuity will not be doable. It is unfortunate however, that the UMTS and WLAN specifications were based on rather different set of requirements and they ended up supporting rather different set of QoS features. Consequently, the QoS consistency turns to be a quite challenging issue. To provide more insight on this issue, we discuss below a list of WLAN QoS deficiencies with respect to UMTS QoS. Apparently, when we target multimedia session continuity across UMTS and WLAN, we should carefully take these deficiencies into consideration and understand their impact. The discussion is based on the assumption that the WLAN MAC layer complies with IEEE 802.11 [5] plus the amendments of IEEE 802.11e [8] and the physical layer complies with IEEE 802.11g [9]. For a good introduction to the QoS aspects of IEEE 802.11e the reader is referred to [10].

1. In a WLAN we cannot support unequal error protection across different media streams. For instance, an AMR payload, an H.263 payload and a HTTP payload will all be subject to the same channel coding (for a given transmission rate) and therefore all media streams will be equally protected against transmission errors, no matter their different bit error rate requirements. On the contrary, in UTRAN different radio transport channels (each with its own channel coding) can be established for streams with different error rate requirements. Thus, error rate can be controlled on a per stream basis.
2. Unequal error protection in a WLAN cannot also be supported between different flows in the same media stream. For instance, the class A and class B bits of an AMR payload [11] will be equally protected against transmission errors, although class B bits can tolerate higher bit error rate. In fact, the WLAN layers are unable to distinguish the different flows of the AMR stream. On the contrary, UTRAN typically employs different radio transport channels for the different AMR flows.
3. Although different media streams may tolerate different residual bit error rates, in a WLAN there is no way to control the residual bit error rate. This is because the WLAN has been optimized to support data streams and therefore enforces a very small residual bit error rate (by using 32-bit long CRC codes). In practice, this may result in increased MAC Service Data Unit (MSDU) loss rate (especially when acknowledges are not used) since all erroneous packets will be dropped even if some of them could be tolerated by the application. Moreover, the channel utilization will be decreased because, according to 802.11 [5], when a station receives an erroneous MSDU it cannot access the channel until after an Extended Inter-Frame Space (EIFS) period.
4. WLAN stations cannot have dedicated radio channels as in UTRAN and therefore the queuing delay and jitter figures could be increased. Note that in 802.11e Hybrid

Coordinator Channel Access (HCCA) mode the stations transmit with a polling discipline and hence delay and jitter will depend on the overall number of stations requesting resources and on the scheduler characteristics. In 802.11e Enhanced Distributed Channel Access (EDCA) mode the stations transmit with a random access discipline tailored to support several different traffic classes.

5. In the WLAN there is no adaptive mechanism for controlling the MSDU loss rate in real-time. The typical way to control MSDU loss rate is via link adaptation with transmission rate change. However, this adaptation is not mandatory in all WLAN stations, it is implementation dependent and, more importantly, it is typically based on some *predefined* loss rate thresholds, which do not correlate directly with the loss rate requirements of the transmitted media streams. The IEEE 802.11g standard allows the transmit power level to vary (the same holds true for 802.11b and 802.11a) but in practice all WLAN stations tend to use the maximum power level at all times, since no fast power control mechanism exists. Note also that in 802.11e EDCA loss rate is even harder to control since collisions are unavoidable.
6. There are no soft handovers in WLAN. Handovers are typically hard in nature, i.e., follow the break-then-make approach, and hence considerable transmission disruptions may exist that result in QoS degradation. Moreover, handovers in 802.11 are solely controlled by the WLAN stations, so the WLAN infrastructure cannot provide tight control of the QoS provisioning. If a WLAN station tends to "ping-pong" between two APs the QoS will be severely affected and the WLAN infrastructure has no means to prevent that.

One of our main conclusions is that the "Service Data Unit (SDU) Error Ratio" and the "Residual Bit Error Ratio" attributes used in UMTS QoS profile (see [12]) cannot be negotiated and controlled in an 802.11 WLAN, mainly due to physical layer restrictions. Also, the WLAN infrastructure is nearly impossible to guarantee a strict QoS level[3] given that there is no standardized mechanism for soft handovers. Of course, these deficiencies represent the price we pay for facilitating simple and cost-efficient WLAN designs.

Nevertheless, it is important to stress out that the above QoS deficiencies of WLANs do not necessarily mean that seamless session continuity from UMTS to WLAN cannot be supported. Under certain conditions, seamless session continuity can be provided (but not guaranteed) even with inefficient utilization of WLAN radio resources (but these are cheap anyway!). To validate our point, in the next sessions we carry out a performance study and evaluate the number of UMTS roamers that can be admitted to the WLAN under certain restrictions, e.g., maintain the QoS level that was experienced in UMTS, respect WLAN policies, etc.

4. Performance Evaluation

Given the aforementioned QoS discrepancies across UMTS and WLAN, and in particular, the limited QoS features of WLAN with respect to UMTS, it is interesting to investigate the feasibility and constraints of seamless QoS provision. In this context, we are interested in investigating the capability of WLAN to support seamless QoS provision for multimedia sessions that have previously been initiated in the UMTS environment. Say, for example, that the WLAN starts accepting UMTS roamers, each one with a video session in progress. Will

[3] It is interesting to observe that IEEE 802.11e carefully refers to the provided QoS as "differentiated" and "parameterized" QoS, not as "guaranteed" QoS.

these video sessions experience a QoS level consistent with the QoS level provided before in the UMTS environment? Under what conditions is this possible? And how many such video sessions can be admitted into the WLAN without compromising the requirements for seamless QoS provision and comply with the possible interworking policy of the WLAN? These are the important questions we are dealing with in this section.

To derive realistic answers to the above questions we consider the interworking scenario illustrated in Fig. 1. In this scenario, there is only one AP, which provides access services to two classes of users: (*a*) the WLAN data users and (*b*) the UMTS roamers, who are UMTS subscribers handed over from UMTS. All UMTS roamers are considered statistically identical and the same holds true for the WLAN data users. In addition, the AP as well as the UMTS roamers comply with the procedures and elements specified in IEEE 802.11i (or Wi-Fi Protected Access) for enhanced security provision. This is required for supporting UMTS-based access control and having the UMTS roamers authenticated and authorized by their UMTS home environment, as specified in [1, 2]. All WLAN stations including the AP support the extended MAC layer specified in IEEE 802.11e and the physical layer specified in IEEE 802.11g. We assume that the transmission rate of WLAN stations is 24 Mbps and that no transmission errors occur (the channel is ideal).

Each WLAN data user has a number of ongoing non-real-time data sessions (e.g., web browsing, email, ftp, etc), which generate an aggregate user traffic described as a Poisson process with 256 kbps mean rate. On the other hand, each UMTS roamer has a uni-directional (uplink) real-time video session in progress, which has been initiated in the UMTS domain and granted the negotiated QoS parameters shown in Table 1[4]. The selection of these parameters is based on [13] and the assumption that H.263 video coding is used with a target bit rate of 64 Kbps. In our simulations the video packet traffic is generated with the aid of the video trace files found in http://trace.eas.asu.edu/TRACE/ltvt.html and the use of Real Time Protocol (RTP) and Real Time Control Protocol (RTCP).

Table 1: The UTRAN QoS values negotiated in UMTS for the H.263 video sessions.

For the interworking scenario discussed above, our main goal is to evaluate how many UMTS roamers the WLAN network can support under the following two constraints:

1. The video streams of all UMTS roamers admitted to the WLAN must experience at least the same QoS level as the one negotiated in the UMTS network (see Table 1). For example, the MAC SDU (MSDU) loss rate in the WLAN must not exceed the corresponding UMTS SDU error ratio, i.e., 10^{-3}. This constraint is required for satisfying the seamless service continuity requirements.
2. The bandwidth available to WLAN data users must not diminish below a predefined threshold. This constraint makes it possible to enforce a bandwidth reservation policy consistent with the WLAN operator's interworking requirements. For example, the WLAN operator may need to ensure that the WLAN data users will have at least 7 Mbps of bandwidth available no matter how many UMTS roamers are admitted into the WLAN. Therefore, UMTS roamers can be served with possibly higher priority than WLAN data users (in order to meet the seamless continuity requirements) but yet they cannot consume all the available bandwidth. For this purpose, the WLAN needs to apply an admission control function, which would reject further association requests from UMTS roamers should the bandwidth reservation limit is reached. In our study,

[4] Note that the values displayed in Table 1 are the values applicable to UTRAN, which could not necessarily be identical to the values in the QoS Information Element [16].

we assume that such admission control function is implemented and we take it into account for calculating the maximum number of UMTS roamers that can be admitted into the WLAN.

5. Performance Results

For performing our evaluations we consider two practical WLAN deployment scenarios: (*a*) *Contention-based Scenario*, where the WLAN AP does not support HCCA access mode and thus both UMTS roamers and WLAN data users employ contention-based channel access, and (*b*) *Contention-Free Scenario*, where the WLAN AP supports HCCA access mode and all UMTS roamers are serviced in this mode (i.e., contention free).

5.1. *Contention-Based Scenario*

In this scenario we assume that both UMTS roamers and WLAN data users use contention-based channel access. A key policy applied by the WLAN indicates that at least *L* Mbps must be available to the WLAN data users. Hence, UMTS roamers can be admitted to the system as long as (*i*) the WLAN can support *L* Mbps of *data* traffic and (*ii*) the QoS experienced by the video streams meets or exceeds the QoS negotiated in the UMTS environment (according to Table 1).

First, we consider a typical case that is expected during the early deployment of UMTS/WLAN interworking, where the WLAN data users use *legacy* terminals with no 802.11e support. These users access the channel by employing the Distributed Coordination Function (DCF) with the following access parameters (see [5]): DCF Inter-Frame Space (DIFS)=2 slots, minimum Contention Window (CWmin)=15, maximum Contention Window (CWmax)=1023 and Persistence Factor (PF)=2. On the contrary, UMTS roamers use 802.11e aware terminals and employ an EDCA access class with the following access parameters (see [8]): Arbitration Inter-Frame Space Number (AIFSN)=3, CWmin=15, CWmax=1023 and PF =2. All terminals maintain uplink buffers that can hold up to 8 maximum sized MSDUs. The terminals of UMTS roamers make every effort to transmit all video packets within their delay bound, which is considered equal to 40 msec for consistency with UMTS. If a video packet, however, is delayed for more than 40 msec, it is dropped. This policy guarantees that the delay experienced by all *successfully transmitted* video packets will be smaller than 40 msec. Hence, the key parameter affecting the QoS of video streams will be the loss rate, which should be kept below the corresponding UMTS limit (10^{-3}).

Our simulation results for the above case reveal that the limiting factor for the maximum number of UMTS roamers in the WLAN is not the bandwidth reservation constraints but rather the loss rate of video streams. As illustrated in Fig. 3a, the MSDU loss rate for video traffic reaches the UMTS negotiated value (10^{-3}) when there are 56 UMTS roamers (or equivalently 56 video streams) for L = 5 Mbps, or 24 UMTS roamers for L = 7 Mbps, or 8 UMTS roamers for L = 8 Mbps. Apparently, when L increases (i.e., when there are more WLAN data users in the system), the transmission delay of video packets is increased and the probability to reach the 40 msec delay bound is increased as well. Hence, the video packet loss rate rises accordingly.

Fig. 3a: The MSDU loss rate for video traffic vs. the number of UMTS roamers admitted in the WLAN.

Fig. 3b: The max delay of 99% of the delivered MSDUs for both the video and the data traffic vs. the number of UMTS roamers admitted in the WLAN.

In Fig. 3b we display the maximum delay of 99% of the successfully delivered packets for both UMTS roamers and WLAN data users. As expected, the delay of video packets is always larger than the delay of WLAN data traffic, since the latter employs a smaller inter-frame space and thus gains priority over video traffic. We also note that the maximum delay experienced by the video packets in the WLAN domain is far less than the limit of 40 msec that was negotiated in the UMTS domain. For example, as shown in Fig. 3b, when L = 7 Mbps and there are 24 UMTS roamers (thus the loss rate is within the UMTS negotiated limit) the maximum delay is about 15 msec. This leads to a significant conclusion: The WLAN can meet or exceed the QoS negotiated in the UMTS domain but with a very inefficient way. Indeed, we can readily derive that, when the transmission rate is 24 Mbps and the WLAN data users offer 7 Mbps aggregate data traffic, there will be about 4.3 Mbps available for UMTS roamers (this corresponds to 47% max channel utilization). However, only up to 1.5 Mbps (24 x 64 kbps) can be utilized for meeting the loss rate requirements.

We further consider another case where both UMTS roamers and WLAN data users are 802.11e aware. The two user classes are mapped however to difference EDCA access classes with the UMTS roamers given higher access priority for meeting their demanding QoS needs. In particular, we assume that the UMTS roamers are mapped to an EDCA access class with the following access parameters: AIFSN=3, CWmin=6, CWmax=511 and PF=2. Similarly, the WLAN data users are mapped to an EDCA access class with the following access parameters: AIFSN=6, CWmin=31, CWmax=1023 and PF=2.

In contrast to the previous case (legacy WLAN data users), our simulation now indicates that the loss rate experienced by video packets is almost negligible since the UMTS roamers are given preferential access to the wireless medium. Therefore, the limiting factor for the maximum number of UMTS roamers in the WLAN is not the loss rate of video streams but rather the bandwidth reservation constraints. Indeed, as displayed in Fig. 4a, when L = 7 Mbps, the MSDU loss rate for data traffic is equal to zero for up to 40 UMTS roamers. Up to this number of roamers, the capacity offered to the WLAN data users is indeed 7 Mbps and hence the bandwidth reservation policy is respected. However, when more than 40 UMTS roamers are admitted to the WLAN then this policy cannot be satisfied as the bandwidth utilized by WLAN data users is quickly diminished.

Fig. 4a: The MSDU loss rate for data traffic vs. the number of UMTS roamers.

Fig. 4b: The max delay of 99% of the delivered MSDUs for both the video and the data traffic vs. the number of UMTS roamers admitted in the WLAN.

From the above, it can be easily deduced that we can experience significant capacity benefits when the WLAN data users become 802.11e aware and the appropriate access parameters are used; e.g., from 24 UMTS roamers with legacy WLAN data users we can climb to 40 UMTS roamers with 802.11e aware WLAN data users. Similar observations can be made in the case of the other two scenarios, namely when L = 5 and L = 8, where the maximum number of UMTS users that can be supported increase to 84 and 12 respectively. Yet, this gain is achieved with a cost on the delay performance of WLAN data users. For example, as illustrated in Fig. 4b, when L = 7 the maximum delay experienced by the WLAN data users when there are 40 UMTS roamers in the system is about 140 msec. In the case of legacy WLAN data users however the delay is about 10 msec when there are 24 UMTS roamers (see Fig. 3b). By comparing Fig. 3b and Fig. 4b, it becomes evident that when the WLAN data users become 802.11e aware, they can still use the same total bandwidth (7 Mbps) but they experience considerably increased delay, which accounts for the considerably more UMTS roamers in the WLAN. Moreover, not only can we have more UMTS roamers admitted in the WLAN but each one will experience reduced delay, i.e., 2-4 msec in Fig. 4b as compared to 7-15 msec in Fig. 3b.

5.2. *Contention-Free Scenario*

In the contention-free scenario it is assumed that all UMTS roamers operate in HCCA mode and therefore they do not content with the WLAN data users. HCCA implements a polling mechanism which allows the Hybrid Coordinator (HC) entity of 802.11e (normally implemented in the AP) to control the access to the wireless channel by assigning Transmission Opportunities (TXOPs) to the requesting WLAN terminals. Since the access to the channel is centrally controlled and there is no contention or collisions, HCCA is appropriate for providing parameterized QoS services with specific bounds. In our simulation each handover of an H.263 video session from UMTS triggers the establishment of a new 802.11e Traffic Stream (TS) with the signalling messages illustrated at the end of Fig. 2. The traffic characteristics and QoS requirements of each TS are described by the Traffic Specification (TSPEC) element shown in Table 2 (see [8] for details on these parameters).

Table 2: The TSPEC values negotiated in WLAN for the H.263 video sessions.

The allocation of TXOPs to UMTS roamers is performed by the *Scheduler* (implemented by the HC) and is based on the QoS requirements defined by the corresponding TSPEC. The scheduler decides for both the polling time of a UMTS roamer as well as the duration of the allocated TXOP. For the purposes of our simulation, it is assumed that the WLAN implements the reference scheduler described in [8], which is also referred to as *Simple Scheduler*. Based on the negotiated Mean Data Rate and Delay Bound of each video session, the Simple Scheduler calculates a fixed *TXOP length* for each UMTS roamer and a *Service Interval* (SI). This results that the scheduler implementing a periodic service pattern by sequentially serving all UMTS roamers every SI time units.

The impact of the WLAN data users, which still operate in contention mode, is considered by limiting the percentage of channel time available to the Simple Scheduler. In particular, assuming again the same bandwidth reservation policy, i.e., allow 7 Mbps minimum bandwidth for the WLAN data users, we readily calculate that about 40% of channel time is left for HCCA operation. Given that constraint, our main objective is to assess the performance of the Simple Scheduler in terms of channel utilization and maximum number of UMTS roamers that can be supported.

Fig. 5a depicts the Channel Occupancy (i.e., the fraction of the total channel time spent in HCCA mode) versus the UMTS roamers admitted in the WLAN. Observe that the occupancy increases linearly and that the 40% of channel capacity available for HCCA is reached for 17 UMTS roamers. This exposes a fairly inefficient channel utilization. Indeed, with 40% of the available radio resources up to approximately 4.8 Mbps can be accommodated, yet the Simple Scheduler manages to accommodate only 1.06 Mbps (17 x 64 kbps).

In contrast to the contention-based scenario, video packets transmitted in HCCA mode are not lost because the scheduler tries to respect the negotiated delay bounds and allocate enough TXOPs to accommodate all traffic load offered by the UMTS roamers. Therefore, the QoS experienced by the UMTS roamers in HCCA mode is affected only by the delay characteristics. Fig. 5b illustrates the delay experienced by the delivered video packets, which is nearly constant throughout the considered range of UMTS roamers and remains below the delay bound negotiated in the UMTS domain (40 msec). It is interesting to note however that this delay is larger than the corresponding delay in contention-based scenario. Comparing for example Fig. 5b with Fig. 4b, we identify that the delay in contention-free scenario increases by nearly 4 times. This is a result of the inefficient TXOP allocation of the Simple Scheduler.

Fig. 5a: Percentage of WLAN channel time spent in HCCA mode versus the number of UMTS roamers.

Fig. 5b: Delay of delivered video packets versus the number of UMTS roamers.

As already pointed out above, the main issue in HCCA operation is the inefficient resources utilization and hence the support of a relatively small number of users (17) as compared to the contention-based scenario. However this should not be attributed to the HCCA mechanism itself but rather to the inherent characteristics of the Simple Scheduler, which employs a greedy, over-provisioning strategy for TXOP allocation in order to meet the QoS requirements. Our simulation results denote that the TXOP Loss Factor, i.e., the percentage of *unused* time allocated to a UMTS roamer (because there were no video packets for transmission), is a bit more than 80%. This basically indicates that the Simple Scheduler allocates four times more radio resources to a UMTS roamer than what is required. This happens because when the Simple Scheduler calculates the TXOP duration per UMTS roamer, it makes a worst case estimation so as to be able to accommodate the largest MSDU size. With Constant Bit Rate (CBR) traffic, where the MSDU size features nearly no variation, this sounds like a reasonably simple and acceptable approach. However, with Variable Bit Rate (VBR) traffic like the considered H.263 video streams, this strategy leads to excessive inefficiency and thus the performance of contention-free scenario does not compare favorably with the performance of contention-based scenario. To improve the scheduling efficiency for VBR traffic, more sophisticated schedulers have been proposed in the technical literature, which adapt the TXOP lengths to the actual size of buffered MSDUs. Examples of such schedulers are presented in [14] and [15].

6. Conclusions

With no doubt, there are still several challenges to be addressed for enabling the seamless interworking of wireless LAN and UMTS networks. As we discussed in this article, the QoS discrepancies between these networks raise some of these challenges. Although the WLAN QoS capabilities have recently been extended considerably with the introduction of IEEE 802.11e, the WLAN is still incapable to support all the QoS features provided by UMTS (e.g., to dynamically control the MSDU error rate, the residual bit error ratio, unequal error protection, etc). This is partially attributed to the characteristics of WLAN physical layer, which has been kept relatively simple in order to enable low-cost designs. As a result, multimedia transmission over WLANs turns to be not so efficient as compared to the UMTS (but definitely less expensive). Vertical handovers present also another challenge for seamless UMTS/WLAN interworking. Since they are usually implemented as mobile-controlled, hard handovers, they bring up considerable QoS concerns, which severely affect the provision of seamless interworking.

In our study of various interworking scenarios, where UMTS subscribers with ongoing real-time video sessions handed over to WLAN, we mainly quantified the maximum number of UMTS subscribers that can be admitted to the WLAN, subject to maintaining the same level of UMTS QoS and respecting the WLAN bandwidth reservation policies. Our results suggest that the WLAN can support seamless continuity of video sessions for only a limited number of UMTS subscribers, which depends on the bandwidth reservations, on the WLAN access parameters and on the QoS requirements of video sessions. The operation of the Simple

Scheduler was proved inefficient for the video traffic and consequently the contention-based scenario resulted to better performance, even though the video traffic had to content with data traffic for channel access.

Acknowledgments

The authors would like to thank ATMEL Hellas for their kind support in the simulation of the Contention-Free scenario.

References

[1] A. K. Salkintzis, "Interworking Techniques and Architectures for WLAN/3G Integration Towards 4G Mobile Data Networks," *IEEE Wireless Communications*, vol. 11, no. 3, pp. 50-61, June 2004.

[2] 3GPP TS 23.234 v6.0.0, "3GPP system to WLAN Interworking; System Description (Release 6)", Mar. 2004.

[3] 3GPP TR 22.934 v6.2.0, "Feasibility study on 3GPP system to WLAN interworking (Release 6)", Sep. 2003.

[4] 3GPP TS 23.060 v5.6.0, "General Packet Radio Service (GPRS); Service description; Stage2 (Release 5)", June 2003.

[5] IEEE standard 802.11, "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications", 1999.

[6] C. Rigney *et al.*, "Remote Authentication Dial In User Services (RADIUS)", *IETF RFC 2138*, April 1997.

[7] P. Calhoun *et al*., "Diameter Base Protocol", *IETF RFC 3588*, Sept. 2003.

[8] IEEE draft standard 802.11e/D8.0, "Medium Access Control (MAC) Quality of Service (QoS) Enhancements", Feb. 2004.

[9] IEEE standard 802.11g, "Further Higher Data Rate Extension in the 2.4 GHz Band", 2003.

[10] Stefan Mangold *et al.*, "Analysis of IEEE 802.11e for QoS support in Wireless LANs", *IEEE Wireless Communications*, no. 6, pp. 40-50, Dec 2003.

[11] 3GPP TS 26.071 v5.0.0, "AMR speech Codec; General description (Release 5)", Dec. 2002.

[12] 3GPP TS 23.107 v5.12.0, "Quality of Service (QoS) concept and architecture (Release 5)", Mar. 2004.

[13] 3GPP TS 26.236 v5.6.0, "Transparent end-to-end Packet-switched Streaming Service (PSS), Protocols and codecs (Release 5)", Sep. 2003.

[14] Grilo A., Macedo M., and Nunes M, "A Scheduling Algorithm for QoS Support in IEEE 802.11e Networks", *IEEE Wireless Communications*, pp. 36-43, June 2003.

[15] Pierre Ansel, Qiang Ni and Thierry Turletti, "An Efficient Scheduling Scheme for 802.11e", in Proc. WiOpt (Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks), Cambridge, UK, March 2004.

[16] 3GPP TS 24.008 v5.12.0, "Mobile radio interface Layer 3 specification; Core network protocols; Stage 3 (Release 5)", June 2004.

Biographies

APOSTOLIS K. SALKINTZIS [SM] (a.k.salkintzis@ieee.org) received his Diploma in 1991 (honors) and his Ph.D. degree in 1997, both from the Department of Electrical and Computer Engineering, Democritus University of Thrace, Xanthi, Greece. In 1999 he was a sessional lecturer at the Department of Electrical and Computer Engineering, University of British Columbia, Canada, and from October 1998 to December 1999 he was also a post-doctoral fellow in the same department. During 1999 he was also a visiting fellow at the Advanced Systems Institute of British Columbia, Canada; during 2000, he was with the Institute of Space Applications and Remote Sensing (ISARS) of the National Observatory of Athens, Greece, where he conducted research on digital satellite communication systems. Since September 1999 he has been with Motorola Inc., working on the design and standardization of wireless communication networks, focusing in particular on GPRS, UMTS, WLANs and TETRA. He has published more than 45 papers in referred journals and conferences and is a co-author and editor of *Mobile Internet* (CRC Press, 2004). He is an editor of *IEEE Wireless Communications* and has served as lead guest editor for a number of special issues of *Mobile Networks and Applications Journal*, *IEEE Personal Communications*, *IEEE Communications Magazine*, etc. His primary research activities lie in the areas of wireless communications and mobile networking, and particularly on mobility management, IP multimedia over mobile networks, mobile network architectures and protocols, and QoS for wireless networks. Until 2002 he was an active participant and contributor in 3GPP, and was an editor of 13 3GPP specifications.

Table 1: The UTRAN QoS values negotiated in UMTS for the H.263 video sessions.

UMTS QoS Parameter	**Parameter Value**	**Comments**
Traffic class	Conversational	
Residual BER	10^{-5}	Corresponds to 16-bit CRC. This cannot be controlled in the WLAN since the supported CRC is always 32 bit long.
SDU error ratio	10^{-3}	
Maximum SDU size	1500 bytes	
Transfer delay	40 msec	
Guaranteed bit rate for uplink	64 kbps	
Maximum bit rate for uplink	128 kbps	
Guaranteed bit rate for downlink	2 kbps	To support RTCP traffic.
Maximum bit rate for downlink	2 kbps	
Delivery order	No	Re-ordering should be taken care by application in order to minimize the transfer delay.
Delivery of erroneous SDUs	No	
Traffic handling priority	Subscribed	Not relevant
SDU format information	Not used	Unequal error protection within the bits of the same SDU is not required.
Allocation/retention priority	Subscribed	Not relevant
Source statistics descriptor	Unknown	Only used for voice and allows the network to assess the utilization of trunk resources.

Table 2: The TSPEC values negotiated in WLAN for the H.263 video sessions.

802.11e TSPEC Parameter	**Parameter Value**	**Comments**
Nominal MSDU Size	320 bytes	Calculated from the H.263 trace file
Maximum MSDU Size	1917 bytes	Calculated from the H.263 trace file
Minimum Service Interval	0 msec	"Don't care"
Maximum Service Interval	40 msec	Considered equal to Delay Bound
Inactivity Interval		Not used
Suspension Interval		Not used
Service Start Time		Not used
Minimum Data Rate		Not used
Mean Data Rate	64 kbps	Calculated from the H.263 trace file
Peak Data Rate	383.4 kbps	Calculated from the H.263 trace file
Maximum Burst Size	1917 bytes	Calculated from the H.263 trace file
Delay Bound	40 msec	For consistency with UMTS (see Table 1)
Minimum PHY Rate	24 Mbps	All stations can transmit with 24 Mbps
Surplus Bandwidth Allowance		Not used
Medium Time		Not used

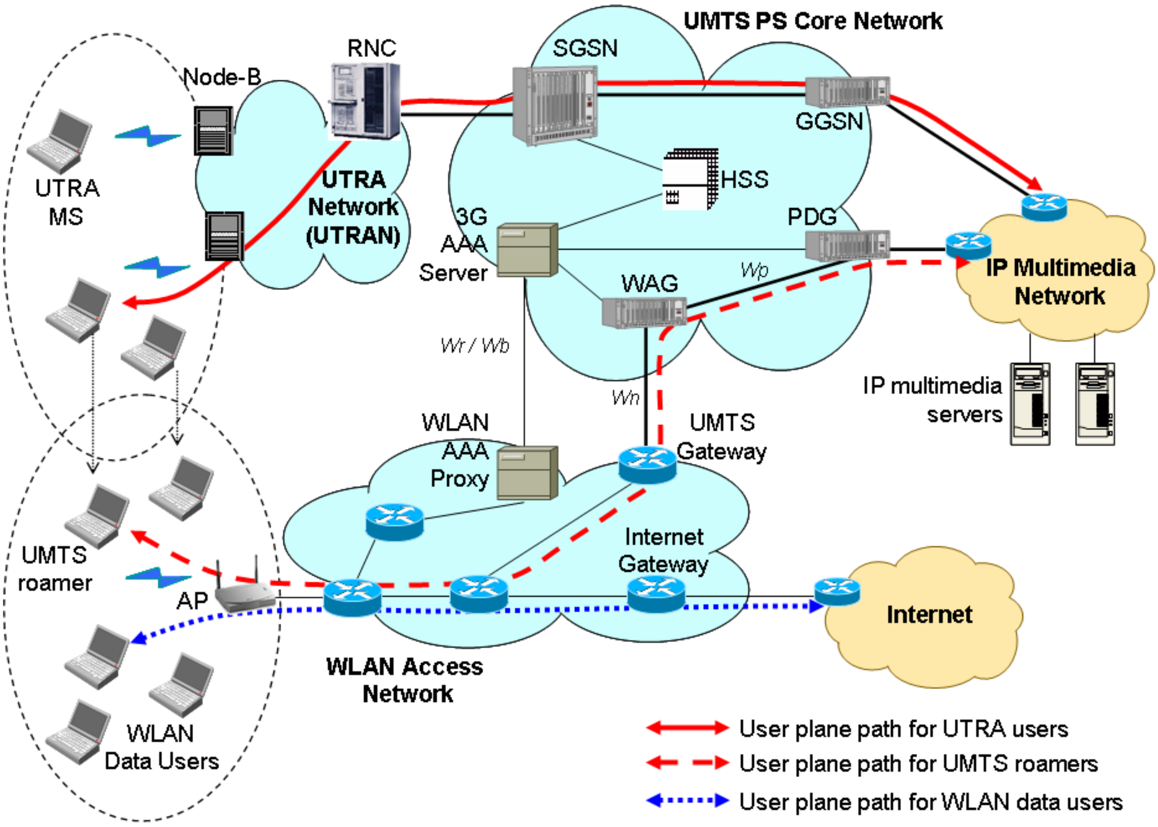

Fig. 1: The considered end-to-end interworking architecture for seamless multimedia session continuity.

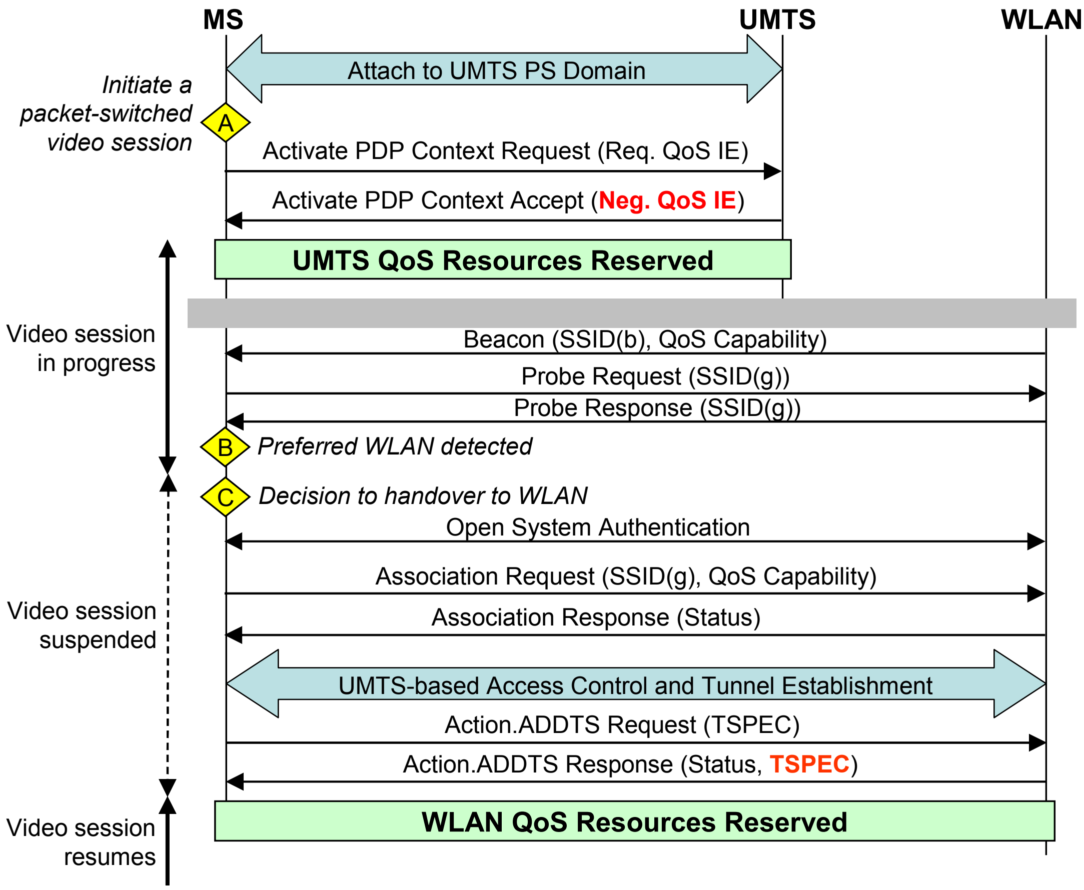

Fig. 2: Typical signalling during handover of a video session from UMTS to WLAN (HCCA availability is assumed).

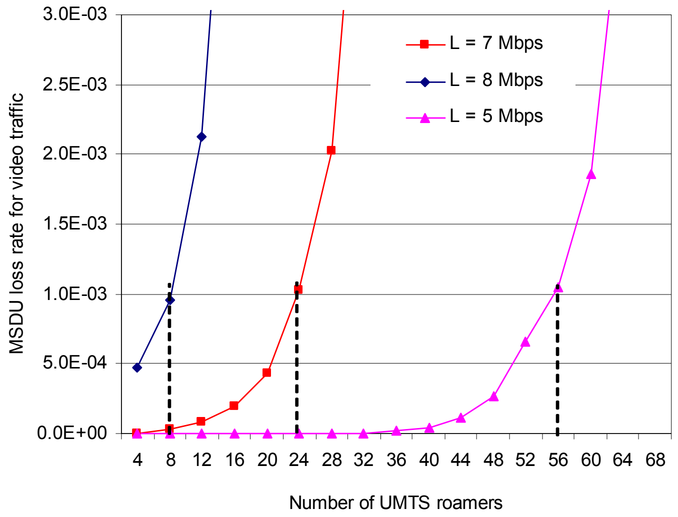

Fig. 3a: The MSDU loss rate for video traffic vs. the number of UMTS roamers admitted in the WLAN.

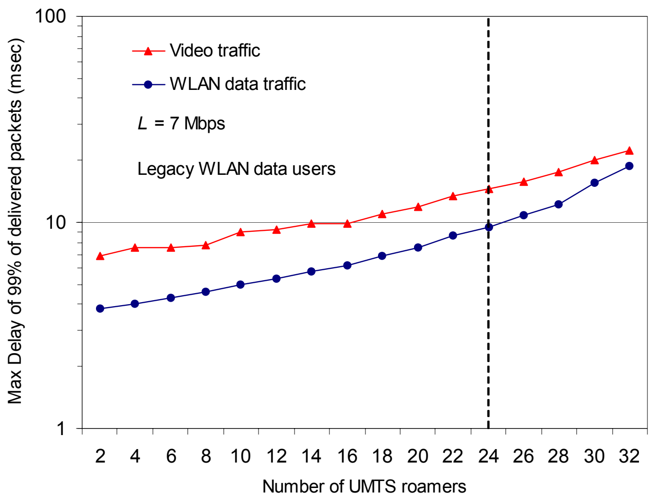

Fig. 3b: The max delay of 99% of the delivered MSDUs for both the video and the data traffic vs. the number of UMTS roamers admitted in the WLAN.

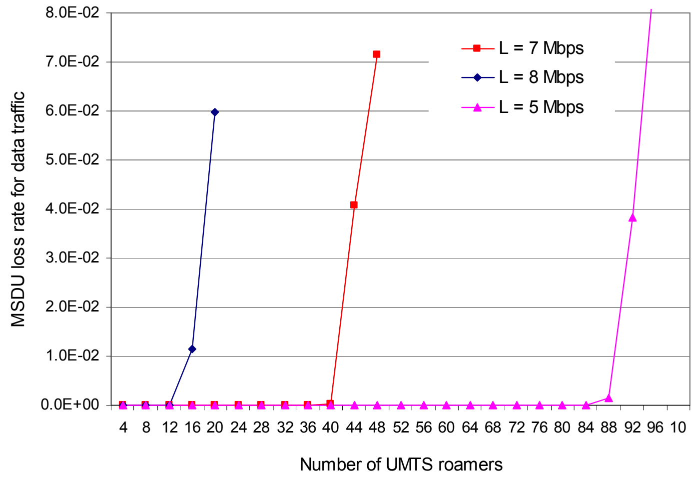

Fig. 4a: The MSDU loss rate for data traffic vs. the number of UMTS roamers

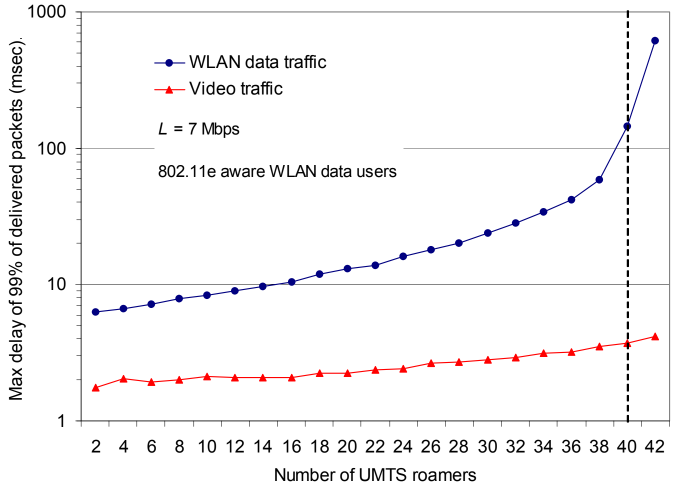

Fig. 4b: The max delay of 99% of the delivered MSDUs for both the video and the data traffic vs. the number of UMTS roamers admitted in the WLAN.

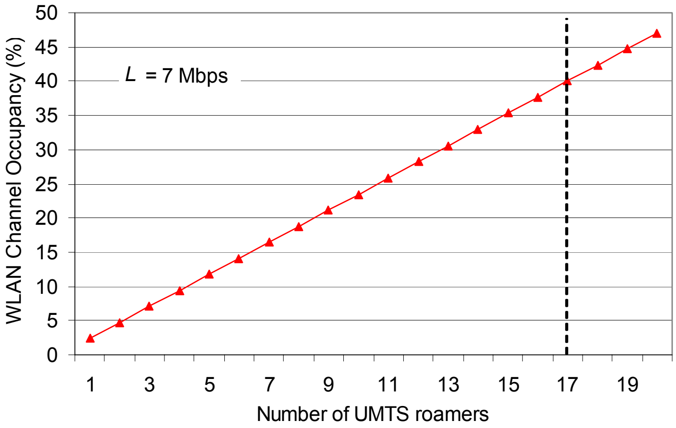

Fig. 5a: Percentage of WLAN channel time spent in HCCA mode versus the number of UMTS roamers.

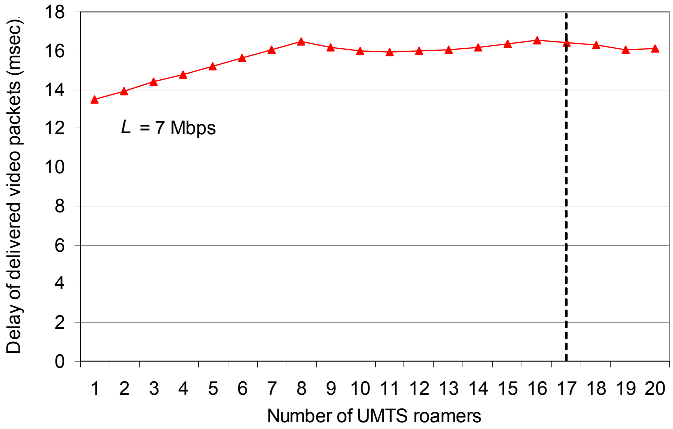

Fig. 5b: Delay of delivered video packets versus the number of UMTS roamers.