Integration of WWAN and WLAN in Hot-Spots

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***Abstract* — This paper presents integration architecture between the wireless wide-area network (WWAN) and wireless local-area network (WLAN) in hot spots. Since the capacity of IEEE 802.11g network is significantly higher than the corresponding WWAN, the integration of two networks is very beneficial. Integrated network can provide seamless mobility between two access technologies and allow continuity of existing sessions. Wide-area coverage can be achieved with proper roaming agreements between different service providers.**

I. INTRODUCTION

THE rapid growth in "anywhere, anytime" high-speed Internet/intranet access is one of the major challenges faced by mobile operators. With increased mobility, the ability to connect mobile terminals (MTs) [such as laptop, personal digital assistance (PDA) and video phone] to the Internet/intranet, and ability to roam across geographical boundaries of heterogeneous networks are also increasing [1,2]. Next generation mobile/wireless networks will be all-IP networks. They will be required to provide enhanced services in large areas, with global convergence, interoperability, and mobility [3]. In order to support global roaming, future networks will need integration and interoperability of mobility management [4].

Both wireless local area network (WLAN) and 3G wireless wide area network (WWAN) are capable of delivering high-speed wireless data services that cannot be provided by earlier 2G cellular networks. Therefore, they seem to compete. However each technology has niche market applications. WLAN can cover only small area and allow limited mobility, but provide higher data rates. Therefore, WLAN is well suited to hotspot coverage, where there is high density of demand for high-data-rate wireless services requiring limited mobility. On the other hand, WWANs, with their well-established voice support, wide coverage, and high mobility, are more suited to areas with moderate or low-density demand for wireless usage requiring high mobility. Therefore, WLAN and WWAN are complementary. The integration of WWAN and WLAN is highly desirable to make wireless multimedia and other high-data-rate services a reality for a large population. A multimedia 3G/WLAN terminal can access high-bandwidth data services where WLAN coverage is offered, while accessing wide area network using 3G at other places. However, this approach alone will only allow limited multi-access functionality. To make multi-access solutions effective, we need an integrated solution to provide seamless mobility between access technologies, allowing continuity of existing sessions. WLAN/WWAN integration promises to offer these capabilities in a seamless manner.

In the standardization arena work is on going in both the 3G Partnership Project (3GPP) and 3GPP2 on WLAN/3G integration. 3GPP has specified an interworking architecture that enables users to access their 2G and 3G data services from WLANs [5]. 3GPP2 has begun to examine the issues of WLAN/3G interworking [6]. They have finalized Stage 1 specifications of the interworking system and initiated the architectural activities.

Several WLAN standardization organizations (in particular ETSI broadband radio access networks (BRAN), IEEE 802.11, and IEEE 802.15) have agreed to set up a joint Wireless Interworking Group (WIG) to deal with the interworking between WLAN and wide area networks. ETSI BRAN is driving this activity primarily from Europe.

Several architectures have been proposed to ensure interoperability between WLAN and WWAN [7]. These architectures rely on Mobile Internet Protocol (MIP).

MIP is the mobility protocol for vertical handoff to provide seamless roaming between access technologies. The main functions of MIP v4 consist of mobile agent discovery, registration with home agent (HA), and delivery of packets using tunneling to the mobile host (MH) via the foreign agent (FA). In this case, the FA in 3G networks resides in gateway GPRS support node (GGSN), FA in WLAN in an access router (AR) and HA in the access router of another WLAN network where operator's IP network resides.

After briefly discussing WLAN and WWAN features, we focus on the integration of two systems; discuss issues, and present different architectures. The objective of the paper is to select appropriate integration architecture for WLAN and WWAN, determine cell capacity and cell radius of the cdma2000 based 3G cellular networks and determine capacity gain that can be achieved by public WLAN in hot spots. The paper is organized as follows. Section II provides background on the wireless technologies. Section III is devoted to the integration architecture of WLAN and WWAN. In Section IV, we discuss the model that is used to determine capacity of multi-cell WLANs. Section V contains analysis results for cell capacity and cell radius of the 3G wireless network and gives capacity gain obtained in moving from WWAN to public WLAN. Section VI provides the conclusions of the study.

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II. BACKGROUND

A. IEEE 802.11 WLANs

IEEE 802.11 defines MAC and Physical layer protocols for wireless LAN communications. The standard has evolved over time, in particular the Physical layer, as shown in Table 1.

Table 1: IEEE 802.11 WLAN parameters

	802.11b	**802.11a**	**802.11g**
Approved	July 99	July 99	June 2003
Modulation	DSSS/CCK	OFDM	OFDM/CCK
Frequency (GHz)	2.4	5-6	2.4
Total Channels	11	12	11
Non-overlapping	3	8	3
Data Rates (Mb/s)	1-11	6-54	6-54
Throughput (Mb/s)	4-7	7-16	7-16

The 802.11b physical layer has been the most popular of the earlier WLAN implementations. It operates in the 2.4GHz ISM band using direct sequence spread spectrum and provides data rates up to 11Mb/s. Three non-overlapping channels are available for use. The 802.11a physical layer operates in the 5-6GHz band and therefore is not interoperable with 802.11b products. It however offers data rates up to 54Mb/s. The more recent 802.11g physical layer is interoperable with 802.11b (giving it wider commercial acceptance) and provides a maximum 54Mb/s data rate.

The prime access method for the MAC is the Distributed Coordination Function (DCF). DCF uses carrier sense multiple access with collision avoidance (CSMA/CA) for channel access. The basic procedure for a node with data to transmit is to wait for the channel to be idle, then back off a random period of time (calculated from a random number between 0 and CW multiplied by the slot time – for the different PHYs, CW and the slot time varies, e.g. for 802.11b, CW starts at 31 with a slot time of 20μs), then transmit the data. The data is successful if an acknowledgement (ACK) is received. Unsuccessful transmissions result in an exponential increase in the back off time and subsequent retransmission. In addition to this basic scheme, a request-to-send (RTS) and clear-to-send (CTS) handshake can occur before the data transmission to ensure all surrounding nodes are aware of the transmission. This reduces the probability of collision, but of course increases the overhead of data transmission.

The typical mode of operation of an IEEE 802.11 WLANs is in infrastructure mode. An infrastructure network is established using access points (APs) for each basic service set (BSS). The AP is similar to a base station in a WWAN, acting as a bridge between wired and wireless networks. The BSS is simply a group of stations, all within range of and associated with a single AP. Large networks are built by connecting several APs over a distribution system.

To access the 802.11 WLAN, the mobile node (MN) first authenticates to the AP and then associates with it to obtain an association identifier. The packet transmissions between the AP and the MN can be optionally protected using a symmetric key-based RC4 encryption known as Wired Equivalent Privacy (WEP). Extensions to the 802.11 security features include Wireless Protected Access (WPA) which provides a higher degree of security than WEP.

Network capacity of a WLAN is roughly the product of throughput multiplied by number of available channels. The throughput depends on overheads of the MAC and physical layers, the number of users sharing the channel and interactions between users (e.g. 802.11b clients can degrade the throughput of 802.11g clients). Various analyses of WLAN throughput have been conducted (e.g. [9]). In Section IV we look at the throughput of 802.11g in a multi-cell network.

B. Third Generation (3G) Cellular Networks

3G cellular networks (cdma2000/UMTS) are designed to provide voice and data services to mobile users. The sustainable data rate per user is hundreds of kbps limited by the total cell capacity of up to 2-3 Mbps. Multimedia users generally exhibit asymmetric bandwidth usage behavior, where the down link bandwidth is usually 2 to 3 times higher than the uplink bandwidth. Also, the high-speed usage tends to cluster in certain areas such as office/apartment building, airport, and conference room and so on. Service providers are looking to deploy low-cost high-speed solution to cover the hot spots either as an extension of 3G or interworking with 3G so that they can utilize effectively the already deployed infrastructure. WLANs offer a viable and attractive choice as being high speed and low cost. The WLAN data service could augment the 3G-packet data service. Users can use dual-mode terminals to access the two networks. The terminals will have two-network interfaces ─ one connects with 3G and the other with WLAN. A typical configuration is to have WLAN form small (micro) cells within large (macro) 3G cells. It is possible to use a common authentication and billing scheme as well as common connectivity to the Internet (see Section III).

C. IP over IEEE 802.11 WLAN

Interconnecting APs through IP forms a WLAN IP network. An access router (AR) connects one or more APs to the network. The APs provide radio interface to the WLAN network, and exchange IP packets with the access routers. They also perform ARP proxy for the mobile nodes (MNs) associated with them. The MN is connected with a single AR at a given point of time, which is called the serving AR. When mobile moves across APs connected through the same AR, an intra-AR handover occurs. The AR coordinates and controls the intra - AP handover. An inter-AR handover occurs when APs involved in the handover are connected to different ARs. In this case, the new AR interacts with MN to perform IP handover. It also initiates and participates in the route repair process to set-up new path inside the network to divert the flow of IP packets destined to the MN to the new AR.

We assume IP protocol suite is used within WLAN, for example RSVP protocol is used to achieve resource reservation and FHMIPv6 protocol to perform handover in the WLAN IP network.

III. INTEGRATION ARCHITECTURE

The WLAN and 3G integration architecture depends on the amount of interdependence it introduces between the two component networks. Two architectures, tightly coupled and loosely coupled interworking have been proposed [7].

The rationale behind the tightly coupled approach (see Fig. 1) is to make the WLAN network appears to 3G core networks as another 3G-access network. The WLAN network would emulate functions that are available in 3G radio access networks. In this architecture, the WLAN gateway network element is introduced to achieve integration. The WLAN gateway hides the details of the WLAN network to the 3G cores, and implements all the 3G protocols (mobility management, authentication etc.) required in 3G-radio access network. MNs are also required to implement the corresponding 3G protocol stack on the top of their standard WLAN network cards, and switch from one physical layer to next as needed. All traffic generated by clients in the WLAN network is injected into the 3G-core network using 3G protocols. These networks would share the same authentication, signaling, transport, and billing infrastructures, independent from the protocols used at the physical layer on the radio interface. This approach has several disadvantages. Since the 3G-core network directly exposes its interfaces to the WLAN network, the same operator will typically required to own both WLAN and the 3G networks. By injecting the WLAN traffic directly into the 3G cores, the setup of the entire 3G networks, as well as the configuration and design of 3G network elements has to be modified to sustain the increased load. It would also mandate the use of 3G-specific authentication mechanisms for authentication on WLANs; forcing WLAN providers to interconnect to 3G carriers' SS7 network to perform authentication procedures.

The loosely coupled approach introduces a new element, the WLAN gateway (see Fig. 1). The gateway connects to the Internet and does not have any direct link to 3G network elements or 3G core network switches. In this approach, the data paths in WLAN and 3G networks are completely separated. The high-speed WLAN data traffic is never injected into the 3G-core network, but end user still experiences seamless access. In this approach, different mechanisms and protocols can handle authentication, billing, and mobility management in the 3G and WLAN parts of the network. This architecture requires that WLAN gateway support MIP functionalities to handle mobility across networks, as well as authentication, authorization, and accounting (AAA) services to interconnect with the 3G's home network AAA servers. This will enable the 3G-service provider to collect WLAN accounting records and generate a unified billing statement for both (3G and WLAN) networks. At the same time, the use of compatible AAA services on the two networks would allow the WLAN gateway to dynamically obtain per-user service policies from their home AAA servers, and to enforce and adapt such policies to the WLAN network. There are several advantages to the loosely coupled integration approach. It allows independent deployment and traffic engineering of WLAN and 3G networks. 3G service providers can benefit from other providers' WLAN deployments without extensive capital investments. At the same time, they can continue to deploy 3G network using well-established engineering techniques and tools. Roaming agreements with many partners can result in widespread coverage, including key hotspot areas, subscribers benefit from having just one service provider for all network access. They no longer need to have separate accounts with providers in different regions, or covering different technologies. This architecture allows a wireless Internet service provider (WISP) to provide its own public WLAN hotspot, interoperate through roaming agreements with WLAN and 3G service providers, or manage a privately installed enterprise WLAN. Because of the flexibility offered by the loosely coupled architecture, it is recommended for integration of WLAN and WWAN.

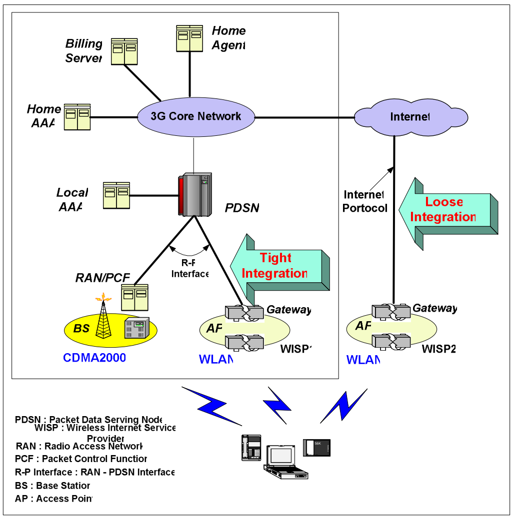

Fig. 1: Tightly coupled versus loosely coupled integration architecture

IV. CAPACITY OF MULTI-CELL WLANS

Several factors influence the capacity of multiple cell WLANs: density of users; traffic requirements of users; the amount of overlap between cells; number of available frequency channels; presence of hidden and exposed terminals etc. Significant effort has been directed towards analyzing the performance of single cell WLANs (e.g. [9]), however due to the many influences on performance, fewer works have addressed the performance of multi-cell WLANs. For this study, we make use of analysis used in [8], which makes several assumptions about a multi-cell network to derive the network capacity from a theoretical single cell capacity.

If the capacity of a single cell is given by Bianchi's model [9], the impact of having multiple cells is related to the capacity reduction caused by interference from other mobile stations in other cells. Assuming cells are separated far enough apart such that two neighboring APs do not interfere with each other, the capacity reduction from the viewpoint of one cell can be categorized as:

1. Stations in the cell receive their full share of capacity.

2. Stations in the cell must share the resource available to them with stations they can hear in neighbor cells.
3. Stations in the cell have a capacity loss due to being affected by the hidden terminal problem (i.e. they lose packets because of two APs or and AP and client transmitting at the same time). For simplicity, we assume the resource obtained by a single station that is affected by the hidden terminal problem is half of its normal share.

The percentage of stations in a cell that fall within each of these categories can be determined by the positions of cells and stations in relation to each other (e.g. distance between APs, range of APs and clients). By knowing these percentages, as well as knowing the impact of the three cases (either full capacity, share with other stations, or halved due to hidden terminals), the total network capacity for a multi-cell WLAN can be calculated (assuming the WLAN spans a large area so that edge effects can be ignored).

Although this approach of calculating network capacity makes simplistic assumptions, and in practice issues such as varying propagation environments and non-uniform node distribution and traffic patterns can further impact performance, it is sufficient to gain indicators of maximum performance, including the impact of basic access versus RTS/CTS and hidden/exposed terminals in a multi-cell WLAN. In Section V we use this approach to determine the capacity of a multi-cell IEEE 802.11g network.

V. ANALYSIS RESULTS

As an example of showing the benefits of integrating WLANs with 3G, we consider a 3G cdma2000 cellular network, which covers an area of 100 km^2. The covered area also has IEEE 802.11g WLAN hot spots, each serving 1000 users in area of approximately 8000 m^2. Our objective is to find capacity gain in moving from the cellular network to IEEE 802.11g public WLAN operating in the hot-spot area (see Figure 2). We use the following data in our analysis.

Table 2: 3G CDMA network parameter values

Parameter	Value
System bandwidth, B_w	10 MHz
CDMA Carrier bandwidth	1.25 MHz
Number of CDMA carriers in a sector	7
Spreading rate, R_c	1.2288 Mcps
Gross information rate per user, R_b	153.6 kb/s
Orthogonality factor, α	0.55
Cell interference due to other cell, β	0.67
$S_j = \langle P_{total,\,j}\rangle / P_{total,\,j}$, δ_i	1.16
Channel activity factor, (υ)	1.0
Required E_b/I_t for data application	0.5 dB
Sector loading, L_{DL}	0.7
3-sector cell gain	2.55

$P_{total,\,j}$ = Total power received from the i-th user including all channels,
$\langle P_{total,\,j}\rangle$ = Average total power received from i-th user

The down link load factor for the cdma2000 cellular network is given as [10]:

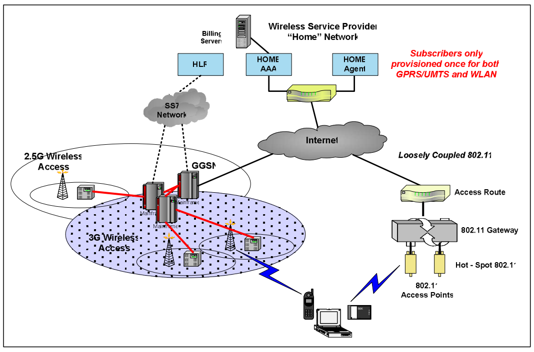

Fig. 2: Integration of 3G and WLAN (Typical solution)

Table 3: IEEE 802.11g WLAN multicell model values

Parameter	Value
AP transmission range, R_a*	21.5m, 12.5m
Client transmission range, R_c	30m
Client sensing range, S_c	60m
Hidden terminal factor, H	2
Assumed number of users per AP	50
Packet size	500 bytes
Cell capacity with basic access	27.73%
Cell capacity with RTS/CTS	24.83%

*Different R_a is given for co-located and cellular layout, respectively

$$L_{DL} = (\alpha+\beta)\sum_{j=1}^{N_{DL}} \frac{1}{1+\dfrac{R_c}{R_b\delta_j\upsilon_j(E_b/I_0)_j}}$$

Using the data listed in Table 2, we get:

$$0.7 = \frac{(0.55+0.67)\times N_{DL}}{1+\dfrac{1.2288\times10^6}{153.6\times10^3\times1.16\times1\times1.122}}$$

We assume all users are distributed throughout the area in a uniform pattern, and have the same data rate requirements, the number of users per sector per carrier, N_{DL} will be:

$$\therefore N_{DL} \approx 4 \quad users \quad per \quad sector \quad per \quad carrier$$

Next, we determine cell capacity as:

$$\begin{aligned} &Cell \quad capacity \\ &\quad = N_{DL}\times R_b \times No.\ of \quad CDMA \quad carriers \times Gain \\ &\quad = 4\times153.6\times7\times2.55 = 10.97 \quad Mbps \\ &or \\ &Number \quad of \quad users \quad per \quad cell = 71.4 \approx 71 \end{aligned}$$

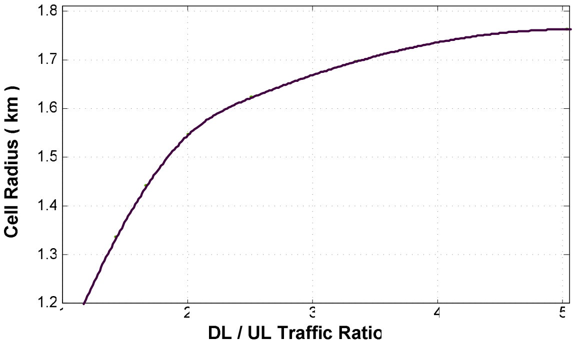

Fig. 3: Cell radius vs DL/UL ratio for CDMA2000

We develop link budgets for the uplink (UL) and downlink (DL) and determine the cell radius using mobile power of 0.125 W and base station power of 1 W (see Figure 3). We obtained a cell radius of about 1.6 km for DL to UL traffic ratio of 3. This suggests that we need about 18 cells to serve 100 km^2 with about 20% cell overlap for cell breathing.

We now determine the capacity of a multi-cell WLAN with frequency reuse. Using the approach described in [8], we look at both a co-located layout of cells, and a typical cellular layout. With three non-overlapping channels available in 802.11g, the co-located layout places three APs at the same position, creating three cells completely overlapping but on separate channels. Of course, to increase coverage of the network, neighboring cells will overlap with cells on the same frequency. The cellular layout places cells on different channels next to each other so that there is no overlap between cells on the same channel. However, in both layouts with asymmetry between ranges of APs (which may be reduced to maximize network capacity) and clients (which are typically larger than APs, due to the large, uncontrollable sensing range) can lead to clients in one cell impacting on clients/APs in other cells. This leads to increase impact of the exposed terminal problem, which may significantly reduce network capacity, as described in [8]. As RTS/CTS amplifies the exposed terminal problem, particularly as the ratio of downlink to uplink traffic increases, it is important to look at basic access and RTS/CTS performance in the presence of different downlink/uplink traffic ratios.

Figure 4 shows the results for the scenario with 1000 users served by 20 APs in both a co-located and cellular layout. Assuming 50 users per AP, the AP range is set to 21.5m in the co-located layout and 12.5m in the cellular layout in order to support the same number of users in the area of 8000 m^2. The results show that with a downlink/uplink traffic ratio of 3, the information rate per user using a cellular layout with basic access is about 154 kb/s. Thus, the gain in the user density in moving from the WWAN to public WLAN in the hot spot will be:

$$WWAN = \frac{71}{2.6 \times (1.6)^2} = 10.67 \quad users \qquad per \quad km^2$$

$$IEEE \quad 802.11g \quad WLAN = \frac{1000}{8000 \times 10^{-4}}$$
$$= 1250 \quad users \quad per \quad km^2$$

$$\therefore Increase \quad in \quad user \quad density$$
$$= 1250 - 10.67 = 1239.33 \quad users \quad per \quad km^2$$

VI. CONCLUSIONS

With IEEE 802.11 WLANs being deployed not only in office environments but also in public areas, it is vital to be able to integrate them into other wireless networks, particularly 3G wireless networks. However, we need to obtain significant capacity increase in order to justify the integration of the two networks. Based on the analysis approach used in [8], we have shown that the capacity of IEEE 802.11g WLANs in a high density multi-cell network is significantly larger than the corresponding 3G networks. Although the analysis does not take into account practical considerations such as non-uniform interference and varying application traffic characteristics, it is sufficient to give an indication of the upper limit on network capacity. We conclude that using the proposed integration architecture, the capacity gain of integrating an 802.11g WLAN for hotspots into a 3G network is very beneficial. Integration between the IEEE 802.11g WLAN and 3G cdma2000 1x networks can provide seamless mobility between two access technologies allowing continuity of existing sessions. The loosely coupled architecture (discussed in Section III) can offer independent deployment and traffic engineering of two networks. Wide-area coverage can be achieved by having roaming agreements between different service providers. Subscribers are also benefited because they deal with only one service provider.

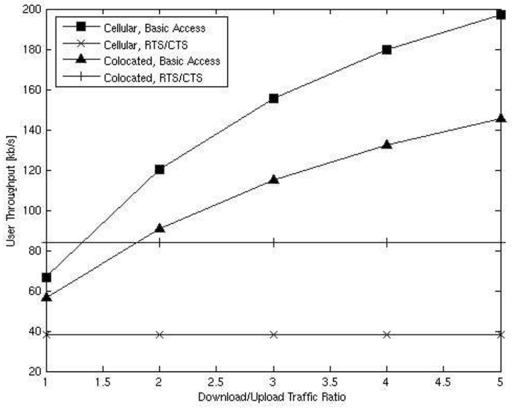

Fig. 4: User throughput vs DL/UL ratio for IEEE 802.11g WLAN

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