Wireless Internet – IMT-2000/Wireless LAN Interworking

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Abstract: **Ongoing standardization effort on 3G cellular systems in 3GPP (UMTS) is based on GPRS core network and promises a global standard for systems capable of offering ubiquitous access to Internet for mobile users. Considered radio access systems (FDD CDMA, TDD CDMA, and EDGE) are optimized for robust mobile use. However, there are alternative relatively high-rate radio interfaces being standardized for WLAN (IEEE 802.11 and HIPERLAN/2) which are capable of delivering significantly higher data rates to static or semi-static terminals with much less overhead. Also WPANs (BLUETOOTH, IEEE 802.15), which will be present in virtually every mobile handset in the near future, are offering low cost and considerable access data rate and thus are very attractive for interworking scenarios. The prospect of using these interfaces as alternative RANs in the modular UMTS architecture is very promising. Additionally, the recent inclusion of M-IP in the UMTS R99 standard opens the way for IP-level interfacing to the core network.**

This article offers an overview into WLAN-Cellular interworking. A brief overview of GPRS, UMTS cellular architectures and relevant WLAN standards is given. Possible interworking architectures are presented.

Index Terms: **WLAN, IEEE 802.11, HIPERLAN/2, IMT-2000, UMTS, 2G, 3G, GSM, GPRS, IP, M-IP, BLUETOOTH, cellular networks, interworking, wireless.**

I. INTRODUCTION

In this article, we are going to present different options in WLAN-Cellular interworking. The objective is to make mobile access to Internet much faster than the current or near-future cellular networks would permit to have. With WLAN-Cellular interworking a cellular operator may be able to offer the convenience of having "desk-top LAN connection"-like quality of service for mobile users.

The second issue that makes this topic attractive is the conquest of new frequency bands for public wireless access to the Internet, as WLANs operate on different and wider frequency bands than the current and near-future cellular networks do. Therefore, not only higher data rates but also the availability of additional spectrum is an attractive feature for a capacity-congested cellular operator.

The topic is relatively new since there were no widely-available WLANs until recently and existing cellular networks' infrastructure did not provide for the capacity needed to support data rates coming from a WLAN, even if it were available.

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This paper covers several standards with their own terminology and acronyms. Table 1 summarizes the main acronyms used in this article and should make reading easier.

Section II gives a very brief overview of considered cellular architectures. Section III presents the new and coming WLAN standards. In Section IV, we present a selection of possible interworking scenarios between the above mentioned standards and also a group of interworking scenarios based on mobile IP. In Section V, we summarize our findings and suggest which architecture seems to be most attractive for future work.

II. ARCHITECTURES OF CONSIDERED CELLULAR SYSTEMS

In this article, we focus on Wireless LAN (WLAN)-Cellular interworking. WLAN standards considered for interworking will be presented in the next section. This section gives an overview of the cellular domain. As for the cellular domain, we strive to stay in line with the International Mobile Telecommunications 2000 (IMT-2000) perspective [1]. One of the prospective IMT-2000 family members is the Global System for Mobile Communications (GSM) based core network architecture with wide-band code-division multiple access (WCDMA) radio interface. The packet switched core network for the GSM based IMT-2000 network evolves from General Packet Radio System (GPRS). The standardization of GSM/GPRS based core network and WCDMA radio access network is currently under way in third Generation Partnership Project (3GPP) [3]. To develop a true world-wide accepted 3G standard, harmonization of the radio interface with CDMA-2000 [4] is being done. This facilitates connection of cdma2000 based radio access network also to GSM/GPRS core network. The work on the first release of specifications, Release 1999 (R99), is nearing its completion. Therefore, discussion on the second release, Release 2000 (R00), has already started at 3GPP. The first major result of that effort is a basic architectural concept.

We are going to introduce the architectures of GPRS, UMTS R99 and UMTS R00 as they are proposed in 3GPP. These three architectures will then be used as examples for interworking with WLAN presented in later sections.

A. General Packet Radio System (GPRS)

GPRS reference architecture is given in Fig. 1. Interfaces Um, Gb (and A) divide the architecture into Mobile Station (MS), Radio Access Network (RAN) and Core Network (CN). MS is represented by Terminal Equipment (TE) and Mobile Terminal (MT). RAN is represented with Base Station Subsystem (BSS) and CN with the other network entities—the infrastructure. TE, such as a laptop, is connected to MT over the R interface. MT communicates with BSS over the radio interface Um. BSS is

Table 1. Acronyms.

2G	Second Generation
3G	Third Generation
3GPP	Third Generation Partnership Project
3GPP-TSG	3GPP Technical Specification Group
A	GSM interface between BSS and MSC
AAA	Authentication, Authorization and Accounting
AAL	ATM Adaptation Layer
AP	Access Point
ATM	Asynchronous Transfer Mode
AuC	Authentication Center
B	GSM interface between MSC and VLR
B-Gb	Broadband Gb
BRAN	Broadband Radio Access Networks (ETSI project)
BSC	Base Station Controller
B-SGSN	Broadband SGSN
BSS	Base Station Subsystem
BSSGP	BSS GPRS Protocol
BT	BLUETOOTH
BTS	Base Transceiver Station
C	GPRS interface between HLR and GMSC
CD	Collision Detection
CDMA	Code Division Multiple Access
CL	Convergence Layer
CN	Core Network
CS	Circuit Switched
CSCF	Call State Control Function
D	GPRS interface between HLR and VLR
DLC	Data Link Control
DNS	Domain Name Server
DS	Direct Sequence
E	GPRS interface between MSC and GMSC
EDGE	Enhanced Data rate for GSM Evolution
EGPRS	Enhanced GPRS
EIR	Equipment Identity Register
ETSI	European Telecommunications Standards Institute
FA	Foreign Agent (M-IP)
FDD	Frequency Division Duplex
FH	Frequency Hopping
FR	Frame Relay
Gb	GPRS interface between BSS and SGSN
Gc	GPRS interface between GGSN and HLR
Gd	GPRS interface between SGSN and SMS-IWMSC
GERAN	GPRS EDGE RAN
Gf	GPRS interface between SGSN and EIR
GFSK	Gaussian Frequency Shift Keying
GGSN	Gateway GSN
Gi	GPRS interface between GGSN and PDN
GMM/SM	GPRS Mobility Management and Session Management
GMSC	Gateway MSC
Gn	GPRS interface between GSNs
Gp	GPRS interface between SGSN and other PLMN
GPRS	General Packet Radio System
Gr	GPRS interface between SGSN and HLR
Gs	GPRS interface between VLR and SGSN
GSM	Global System for Mobile Communications
GSM-RF	GSM radio interface physical protocol
GSN	GPRS Support Node
GTP	GPRS Tunneling Protocol
GTP-U	GTP User plane
H.323	ITU recommendation for multimedia communications over LAN
HA	Home Agent (M-IP)
HID	Human Interface Device (in BT)
HLR	Home Location Register
HSS	Home Subscriber Server (UMTS R00)
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IGSN	Internet GPRS Support Node
IMT-2000	International Mobile Communications 2000
IP	Internet Protocol
IPsec	IP security protocol
IR	Infrared
ISDN	Integrated Services Digital Network
ISM	Industrial, Scientific and Medical
ISP	Internet Service Provider
ISUP	SS7 ISDN User Part
ITU	International Telecommunication Union
ITUN	SS7 ISUP Tunneling (Adaptation layer for ISUP and SCCP for SCTP)
Iu	UMTS interface between RAN and CN
IuCS	Circuit Switched Iu interface (UMTS)
IuPS	Packet Switched Iu interface (UMTS)
IWMSC	Inter-Working MSC
IWU	Inter-Working Unit
L1	Layer 1
L2	Layer 2
L2CAP	Link Layer Control and Adaptation Protocol (in BT)
LAN	Local Area Network
LLC	Logical Link Control protocol (in GPRS)
LMP	Link Manager Protocol (in BT)
MAC	Medium Access Control
MAP	Mobile Application Part (GSM)
ME	Mobile Equipment
ME	Management Entity (in BT)
MGW	Media Gateway
M-IP	Mobile IP
MCU	Multipoint Control Unit (H.323)
MGCF	Media Gateway Control Function
MMAC	Multimedia Mobile Access Communication system
MRF	Media Resource Function
MS	Mobile Station
MSC	Mobile Switching Center
MT	Mobile Terminal
MTP3-B	Message Transfer Part level 3 (SS7)
NAI	Network Access Identifier
NII	National Information Infrastructure
Node B	Base Transceiver Station in UMTS
OFDM	Orthogonal Frequency Division Multiplex
PCMCIA	Personal Computer Memory Card International Association
PDN	Public Data Network
PDP	Packet Data Protocol
PDU	Protocol Data Unit
PHY	Physical
PLMN	Public Land Mobile Network
PPP	Point-to-Point Protocol
PS	Packet Switched
PSTN	Public Switched Telephone Network
QoS	Quality of Service
R	GPRS interface between TE and MT
R00	Release 2000
R99	Release 1999
RAN	Radio Access Network
RANAP	RAN Application Part
RFCOMM	Serial Cable Emulation Protocol in BT
RLC	Radio Link Control protocol (in GPRS)
RNC	Radio Network Controller (in UMTS)
RNS	Radio Network Subsystem
R-SGW	Roaming Signaling Gateway
RT	Real Time
SA	System Architecture
SAP	Service Access Point
SCCP	Signaling Connection Control Part (SS7)
SCTP	Simple Control Transport Protocol
SDP	Service Discovery Protocol (in BT)
SGSN	Serving GSN
sigtran	Signaling Transport working group at IETF
SIM	Subscriber Identity Module
SIP	Session Initiation Protocol
SMS	Short Message Service
SMS-IWMSC	SMS Inter-Working MSC
SM-SC	SMS Service Center

Table 1. *(continued.)*

SNDCP	Subnetwork Dependent Convergence Protocol (in GPRS)
SS7	Signaling System number 7
SSCF-NNI	Service Specific Coordination Function – Network Node Interface (SS7)
SSCS	Service-Specific Convergence Sublayer
SSCOP	Service Specific Connection Oriented Protocol (SS7)
TCP	Transmission Control Protocol (TCP/IP)
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TE	Terminal Equipment
T-SGW	Transport Signaling Gateway
UDP	User Datagram Protocol (UDP/IP)
U-GTP	User GTP
Um	GPRS radio interface (between MT and BSS)
UMS	User Mobility Server
UMTS	Universal Mobile Telecommunications System
UNI	User-Network Interface (ATM)
UP	User Plane
U-PDP	User Packet Data Protocol
USIM	UMTS SIM
UTRAN	UMTS Terrestrial Radio Access Network
Uu	UMTS radio interface
VLR	Visitors Location Register
VPN	Virtual Private Network
WCDMA	Wide-band CDMA
WG	Working Group
WLAN	Wireless LAN
WPAN	Wireless Personal Area Network

composed of Base Station Controller (BSC) and Base Transceiver Station (BTS). In GPRS architecture, due to the legacy circuit-switched GSM networks, a BSS connects to Mobile Switching Center (MSC)/Visitors Location Register (VLR) over the interface A. An operator can have several MSCs. The one that connects the circuit-switched side to the outside world is called Gateway MSC (GMSC). GPRS supports Short Message Service (SMS). SMS Service Center (SM-SC) sends and receives SMS over SMS-GMSC/SMS-IWMSC (Inter Working MSC). In GPRS, SMS messages are transmitted over SGSN. We will not further elaborate on the GSM network part as they are well described elsewhere [5].

As for the packet-switched side, the basic node in the packet network is called GPRS Support Note (GSN). The one that is attached to user's BSS over the Gb interface is called Serving GSN (SGSN). SGSN keeps track of the individual MSs' locations and performs security functions and access control. All SGSNs are connected to the IP core network. The gateway GSN that interfaces the GPRS network to the outside world is called Gateway GSN (GGSN). The interface between SGSN and GGSN is denoted as Gn. SGSN is connected to Home Location Register (HLR) over the Gr interface. SGSN can connect to VLR over Gs to enhance and coordinate the packet and circuit-switched services, such as paging.

Protocol stacks of the GPRS core network are shown in Fig. 2. The figure shows both the transmission plane and the control plane. From the protocol stack of the Gn interface one can see that the core network is IP-based. User packet data protocol (U-PDP) can be either IP or X.25. Packets arriving from the outside networks at GGSN are encapsulated in the GPRS Tunneling Protocol (GTP). If User Packet Data Protocol (U-PDP) is IP, GTP Protocol Data Units (PDUs) are transported on UDP/IP.

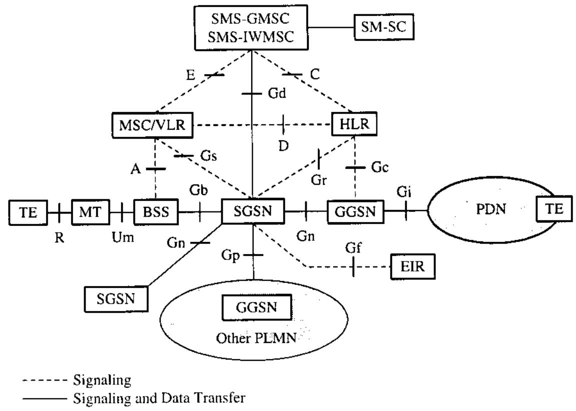

Fig. 1. GPRS reference architecture.

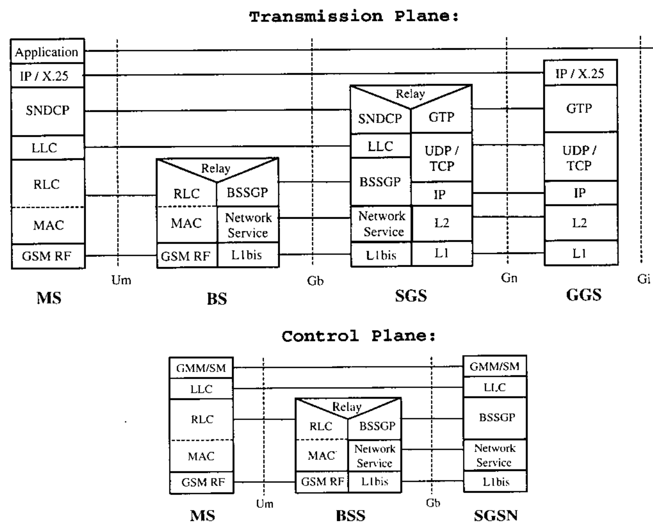

Fig. 2. GPRS transmission and control planes.

If U-PDP is X.25, GTP PDUs are transported with TCP/IP. The core network is a private network with IP routing. SGSN decapsulates the U-PDP PDUs and transports them over the radio access network to the Mobile Station (MS = MT + TE).

In more detail, SGSN relays U-PDUs and encapsulates them into Subnetwork Dependent Convergence Protocol (SNDCP). SNDCP maps network-level characteristics onto the characteristics of the underlying network and performs compression.

Logical Link Control (LLC) layer provides a highly reliable ciphered logical link. LLC is independent of the underlying radio interface protocols in order to allow for introduction of alternative GPRS radio solutions with minimum changes to the core network.

Base Station System GPRS Protocol (BSSGP) layer conveys routing- and Quality of Service (QoS)-related information between BSS and SGSN. BSSGP does not perform error correction. Network Service between BSS and SGSN is based on Frame Relay.

Radio Link Control (RLC) layer provides a radio-solution-dependent reliable link. Medium Access Control (MAC) controls the access signaling procedures for the radio channel, and the mapping of LLC frames onto the GSM physical channel.

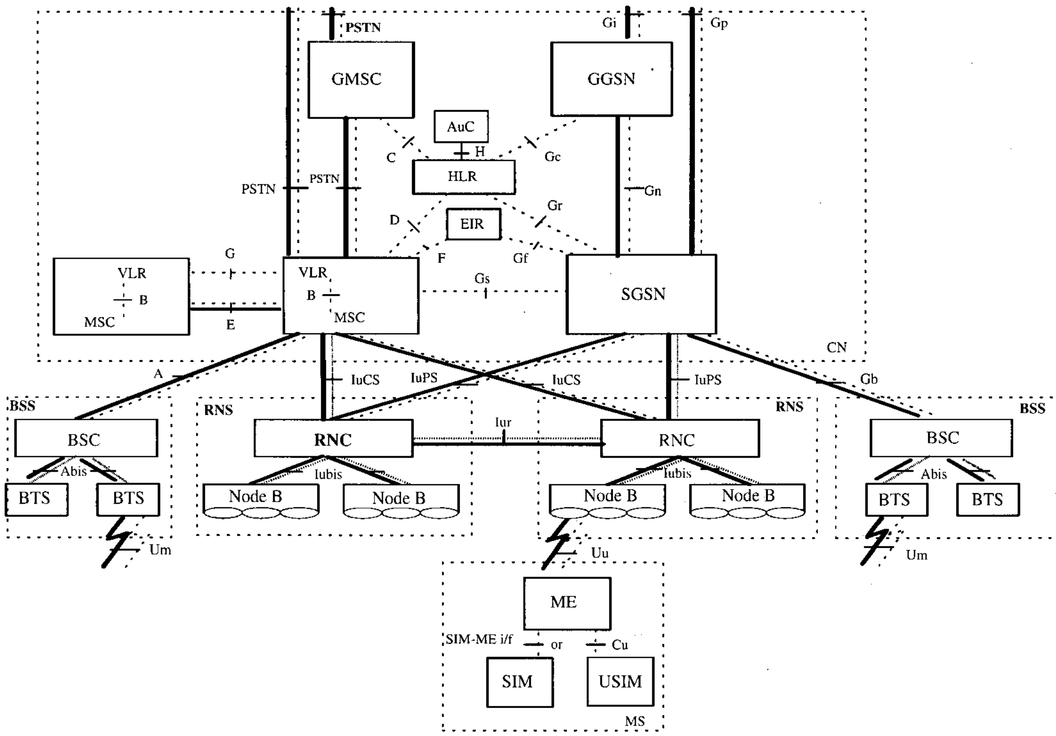

Fig. 3. UMTS R99 reference architecture.

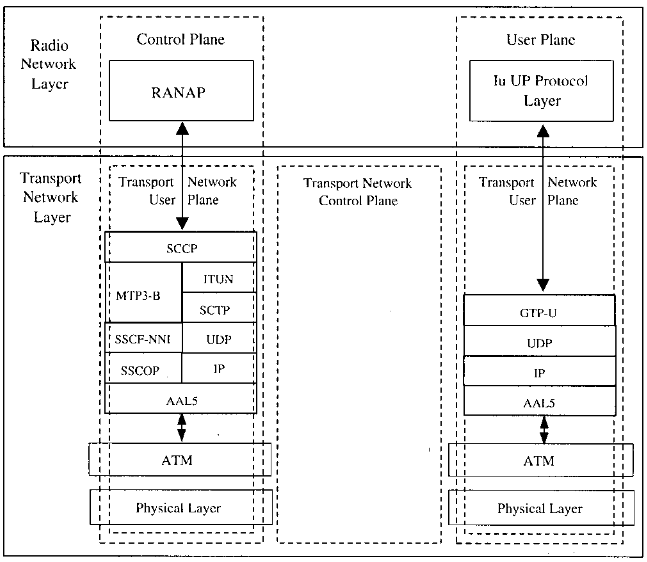

Fig. 4. UMTS R99 IuPS interface.

In the control plane, GPRS Mobility Management and Session Management (GMM/SM) protocol is transported between SGSN and MS on LLC layer. It supports mobility management functionality, security, PDP context activation/deactivation, etc. A more detailed overview can be found in [6].

B. Universal Mobile Telecommunications System (UMTS) R99

Fig. 3 shows UMTS reference architecture for Release 1999 [7]. UMTS architectural design clearly divides the network into two domains: radio access network (RAN) and core network (CN). The interface between them is denoted as Iu. Iu interface was designed with the objective of supporting alternative RANs. The original idea was to have satellite and terrestrial RANs, but only the UMTS Terrestrial Radio Access Network (UTRAN) is being standardized at 3GPP right now. Fig. 3 also shows that there are two instances of Iu interface, the Packet-Switched Iu (IuPS) and the Circuit-Switched Iu (IuCS). IuCS supports legacy GSM core networks and interfaces UTRAN to MSC.

Unlike the terminology used in GPRS, Base Station Controller is now called Radio Network Controller (RNC) and Base Transceiver Station is called Node B.

Mobile Equipment (ME) is connected to RAN over the UMTS radio interface Uu. RAN is connected to SGSN (or MSC) over the before mentioned interface Iu. The core network looks from architectural point of view like GPRS.

Fig. 3 also shows that in a UMTS ME either a GSM Subscriber Identity Module (SIM) or UMTS SIM (USIM) can be used. This allows user identity roaming between 2G and 3G terminals.

Even though we discuss the choice of the proper interface for WLAN/UMTS interworking in the following sections, from the above description we see that, when cellular mobility management is reused, the Iu interface is going to be the likely the WLAN/UMTS interworking interface of choice. The protocol stack of Iu interface [8] is shown in Fig. 4. This figure shows the packet switched instance of the interface.

Unlike in GPRS, in UMTS the user GTP (U-GTP) protocol termination point is in RAN and thus it traverses the Iu interface. GTP-U is transported over UDP/IP/AAL5/ATM. In the control

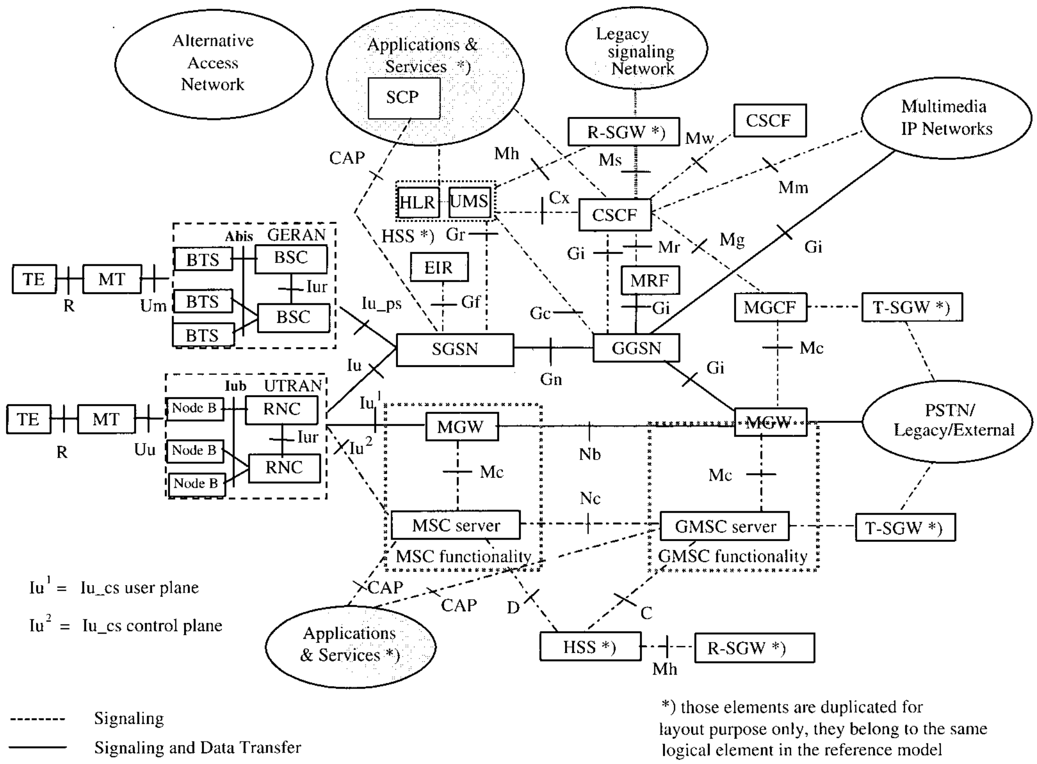

Fig. 5. UMTS R00 reference architecture.

plane is RAN Application Part (RANAP) protocol. The transport of this protocol has two options. The left stack is Broadband SS7. The right stack is Simple Control Transport Protocol (SCTP/IP) submitted to IETF by sigtran working group [9].

C. Universal Mobile Telecommunications System (UMTS) R00

As it has been mentioned above, technical specifications of UMTS R99 are being finalized. 3GPP has started activity to lay out architecture for UMTS R00. The main driver behind is "All-IP core network [10]."

The aim of the all IP architecture is to allow operators to deploy IP technology to deliver third Generation services, i.e., an architecture based on packet technologies and IP telephony for simultaneous real time and non real time services. To emphasize, even circuit-switched voice will be transported over IP. This architecture is based on an evolution from Release 99 specifications. In other words, it must be backwards compatible with the previous release. This is a very important point, especially if one considers that R00 CN has to support R99 circuit-switched terminals and the installed R99 infrastructure by the time R00 is deployed.

The IP network should provide wireless mobility access based on GERAN (GPRS EDGE RAN) and UTRAN with a common core network, based an evolution of GPRS, for both.

UMTS R00 proposed architecture is shown in Fig. 5. This architecture shows also an "Alternative Access Network" which could be WLAN.

As for the core network, naming nodes such as SGSN and GGSN and interfaces between them are preserved from R99. HLR functionality (user profiles and location) is now provided by Home Subscriber Server (HSS). It may store/generate also IETF features, such as security data, policies. It provides other All-IP features, such as DNS, AAA, etc.

The key new addition is the Call State Control Function (CSCF) which controls signaling to the multimedia IP network. It has not been decided yet if it would be H.323 or SIP-based. Roaming Signaling Gateway (R-SGW) interfaces CSCF to legacy mobile signaling network. Media Gateway (MGW) is a gateway to legacy or external networks. It is also used to interface UTRAN to All-IP CN. Over Iu interface, it may support media conversion, bearer control and possibly even payload processing (codec, conference bridge, etc.). Multimedia Resource Function (MRF) performs multiparty calls (similarly to MCU in H.323). Media Gateway Control Function (MGCF) performs conversion between legacy and R00 call control function and selects CSCF for incoming calls from legacy networks. Transport Signaling Gateway (T-SGW) maps signaling to/from legacy networks on IP bearer and sends them to MGCF.

Fig. 5 also shows the evolutionary aspect by highlighting how the network may migrate from R99 by showing how to handle R99 CS part. MSC Server comprises mainly call control and mobility control parts of GSM/UMTS R99 MSC.

Interfaces and detailed functional description of the new network elements have not been described yet.

D. Mobile IP in UMTS

3GPP-TSG System Architecture Working Group 2 submitted a technical report [11] to 3GPP which outlines introduction of Mobile IP (M-IP) into UMTS in three steps. Step one, that has already become part of UMTS R99, introduces M-IP Foreign

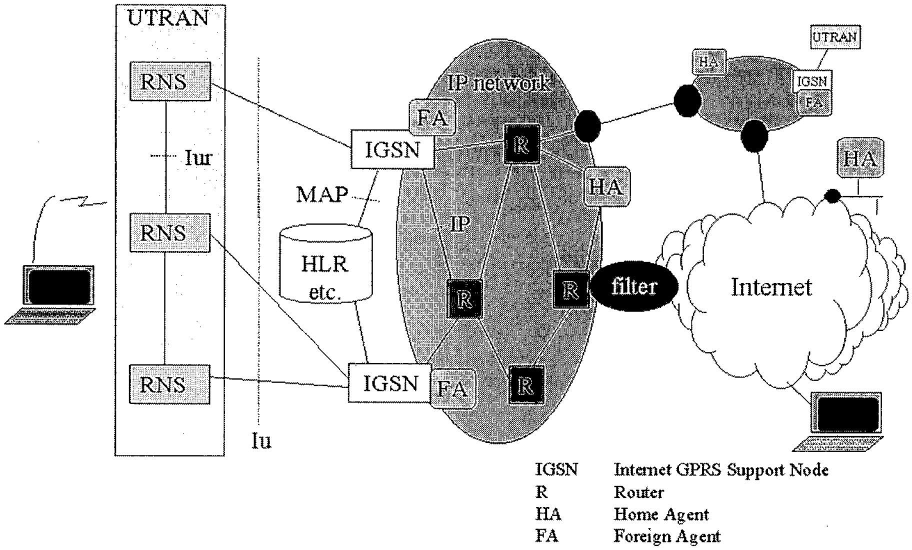

Fig. 6. M-IP in UMTS R00, step 3.

Agent (FA) functionality to GGSN. Step two allows for a GGSN handover using M-IP. Step three, shown in Fig. 6, merges GGSN and SGSN into Internet GPRS Support Node (IGSN). All mobility within the CN is done with M-IP.

M-IP in UMTS should support Network Access Identifier (NAI)-based Roaming procedures and IETF standard AAA procedures. It should provide end to end Quality of Service (QoS) or service differentiation according to IETF standards for IP packet transport and support of Mobile IP with Challenge/Response based authentication and NAI extension. The goal is to achieve interoperability between UMTS operators, corporations and ISPs offering Mobile IP.

Since most of the referred IETF standards are under development it will certainly require coordination and concentrated effort of both 3GPP and IETF to meet the expected deadline for UMTS R00.

With this section, we have very briefly covered cellular architectures on the GPRS-UMTS path towards IMT-2000. In the following section, we will briefly review relevant WLAN standards.

III. CONSIDERED WLAN STANDARDS

This section gives a brief overview of some WLAN standards and BLUETOOTH which may also be considered as a very short-range WLAN.

The 2 Mb/s IEEE WLAN standard, IEEE 802.11 [12], was released in 1997. It operates on ISM band (2.4 GHz) and offers three physical interfaces: Direct Sequence (DS), Frequency Hopping (FH) and Infrared (IR). At about the same time, 20 Mb/s HIPERLAN/1 standard [13] for 5 GHz band was released by ETSI [2]. 802.11 has had moderate commercial success while HIPERLAN/1 has not appeared in the market at all.

Very soon afterwards, standardization of new high-rate versions of these standards has started. It is IEEE 802.11a for 5 GHz NII band and 802.11b for 2.4 GHz ISM band. In Europe, it is ETSI BRAN HIPERLAN/2 for 5 GHz. A brief comparison of these standards is given in Fig. 7. It is worth noting that 802.11a and HIPERLAN/2 (and MMAC in Japan) have harmonized PHY layers, all OFDM with 54 Mb/s.

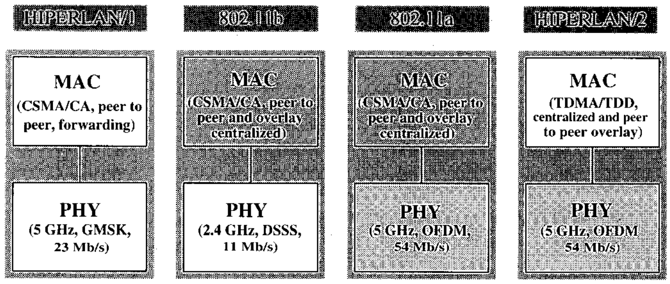

Fig. 7. WLAN standards.

The difference between 802.11a and HIPERLAN/2 lies in the higher layers. 802.11a/b is basically a wireless Ethernet with Carrier Sense Multiple Access / Collision Avoidance MAC. (Ethernet uses Collision Detection – CD.) HIPERLAN/2 is centralized, using TDD/TDMA and thus allows for efficient QoS support over the radio interface.

Technical standardization work on 802.11a/b has been concluded and HIPERLAN/2 standard is to be released in early 2000.

It is quite interesting to see the position of WLAN and cellular standards in terms of range and speed to see that they are quite complementary (Fig. 8).

We will not further elaborate on the IEEE 802.11a/b standards and accept that they are wireless Ethernets.

As for the HIPERLAN/2 standard [14], there are some unique features worth mentioning here.

Fig. 9 shows HIPERLAN/2 Convergence Layer (CL). The Convergence Layer can be separated into two parts, a cell based part and a packet based part. The cell based part of the Convergence Layer [15] offers services to higher layers that use data units of a fixed size, such as ATM. Cell based Convergence

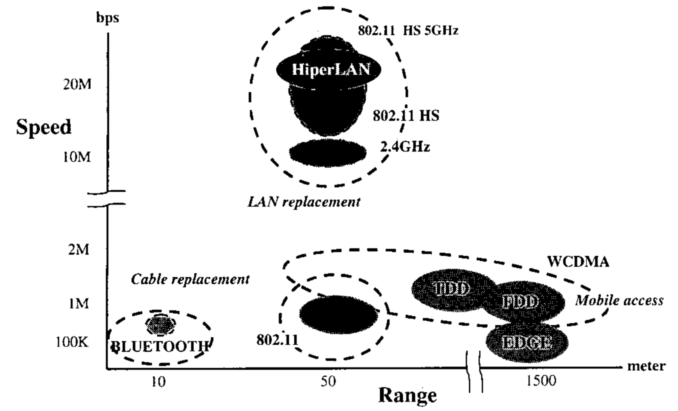

Fig. 8. WLANs position relative to cellular standards with respect to range and data rates.

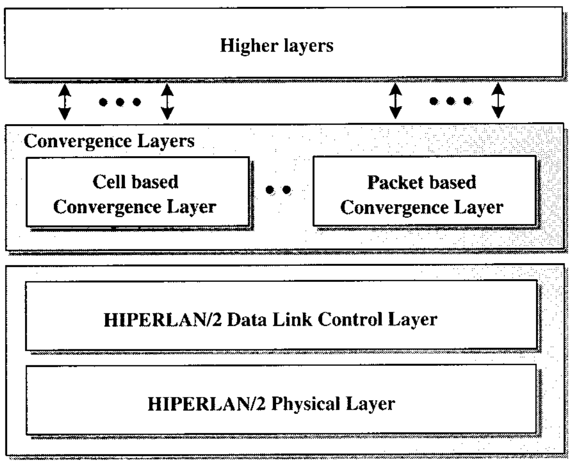

Fig. 9. HIPERLAN/2 Convergence Layers.

Layer is split into two parts, a lower common part and an upper UNI service specific part. The Packet based Convergence Layer [16] (Fig. 10) offers services to higher layers which use packets or frames of variable size. Typical examples of these are Ethernet and the Internet Protocol suite. The Packet based CL consists of two main parts, a Common Part and a Service Specific Convergence Sublayer (SSCS). BRAN envisions that several SSCS will be specified in future, including UMTS SSCS.

Another unique feature of HIPERLAN/2 is that it supports restricted user mobility within a local service area.

BLUETOOTH (BT) standard is owned by the BLUETOOTH Special Interest Group [17]. BT was originally intended to offer very short range (10 m) wireless replacement for serial link between devices, such as a mobile phone and a headset. As the work on the standard progressed several scenarios emerged: data and voice access point, cable replacement and personal ad hoc networking, etc.

BT works in 2.4 GHz IMS band using frequency hopping of 1600 hops/s with modulation of 1 Msymbol/s (GFSK).

BT protocol stack is shown in Fig. 11. Link Layer Control and Adaptation Protocol (L2CAP) is a simple data link protocol for the baseband. It also offers the option of QoS specification per connection. RFCOMM (based on GSM TS07.10) emulates

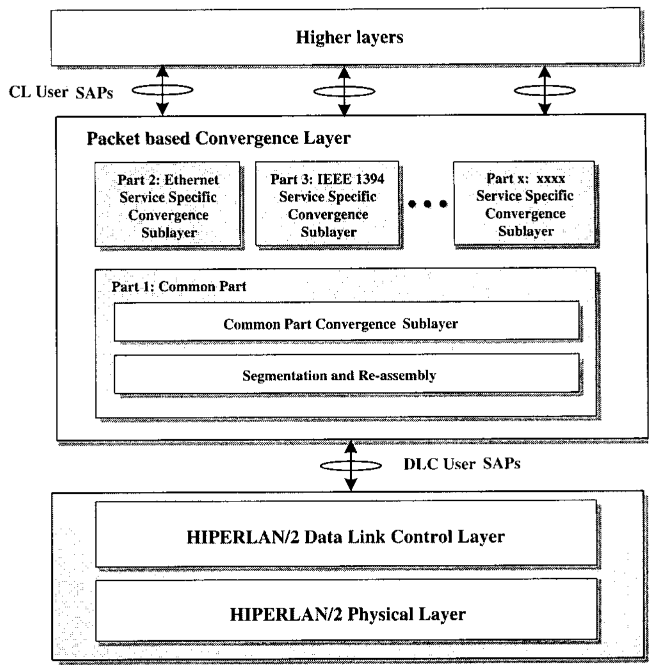

Fig. 10. HIPERLAN/2 Packet based Convergence Layer – user plane.

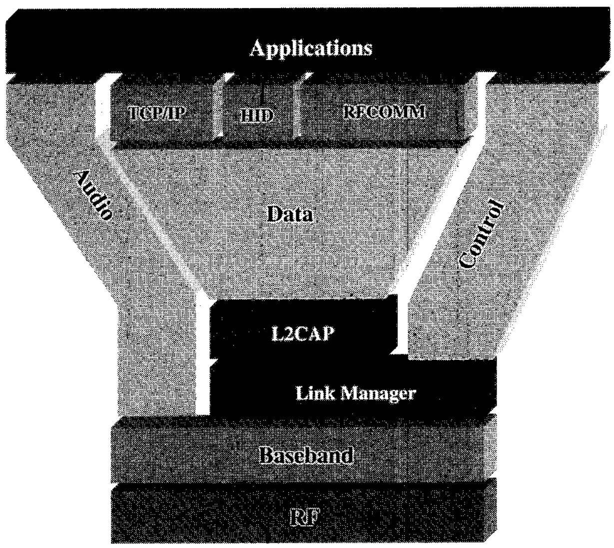

Fig. 11. BLUETOOTH reference architecture.

a serial port, which could be used to access LAN with IP/PPP stack on top of it.

BT was adopted by IEEE 802.15 (Personal Area Networks) [18] as a starting point for further development. In our opinion, there are three important changes/improvements that 802.15 is probably going to contribute: a backwards compatible (bimodal) high rate WPAN of 20 Mb/s, up-scaleable system to 5.8 GHz band, and IEEE 802-conformant protocol stack.

IV. INTERWORKING ARCHITECTURES

The first publication on WLAN/Cellular interworking going into architectural details was an internal BRAN publication

[19]. Our Iu and Gb interworking architectures are based on it. It considered HIPERLAN/2-GPRS and HIPERLAN/2-UMTS interworking. Regarding IP-level interworking architectures, there are quite a few very interesting projects considering M-IP based interworking for wireless networks, such as Monarch [20], Crosspoint [21], Daedalus [22] (effectively a successor of project BARWAN), and others. These projects consider M-IP mobility over wireless networks but do not attempt to integrate them into the cellular infrastructure, from the point of view of charging/billing.

We will first elaborate on architectures where WLAN access network replaces cellular radio access network. Then we will look into possible architectures using M-IP for interworking.

Whatever the interworking architecture will be, the role of multi-mode terminals is an issue to consider. Having just a single mode (WLAN) terminal, such as a PCMCIA card, would be easier to implement and would already offer worldwide roaming between WLAN access zones. It may also allow user to keep his/her cellular (or home) IP identity and thus be reachable for incoming calls or connections worldwide. Dual-mode (WLAN and cellular) terminals are more difficult to manufacture but would offer seamless interworking for roaming from lower-rate higher tier network (cellular) into higher-rate lower tier network (WLAN access zones) and back.

As we have seen in previous sections, there is a wide choice of interfaces in the cellular systems to choose from for the purpose of interworking with WLANs. Not all of them, however, are suitable for doing it in an efficient way. There are several criteria for choosing an "optimal" interface for interworking.

One, probably the main criterion, is that the interface has to be standardized in a sufficient detail to allow for a clean and multi-vendor interoperable interworking systems.

An equally important fact to consider is that interfaces partition the system into logical nodes, each with its own logical functionality. When considering interworking with WLAN, it is crucial to interface it in such a way that the functionality of the part of the network that is replaced by the WLAN "cloud" provides equivalent functions to the "replaced" part of the cellular network. In case of WLAN, as we have seen, the WLAN standards usually deal only with the physical layer and lower parts of data link layer. This would lead us to simply replacing the cellular radio with WLAN radio. Although this is possible it is by no means efficacious since many higher layers of the cellular protocols are tailored for difficult outdoor environment with highly mobile users and are not necessary for WLAN to operate properly.

WLANs are primarily designed for connection to LANs. Therefore, we could reuse LAN (or WLAN for that purpose) as a distribution network replacing the cellular radio access network. The remaining problem, mobility between WLAN access points (APs) can be solved either by WLAN AP handover mechanisms provided in the WLAN, such as those in HIPERLAN/2, or by using some of the IP micro-mobility architectures submitted to IETF or eventually, reuse mobility management from the cellular core network. This topic, however, is out of scope of this article. We will further assume that, as an example, Ethernet LAN is used to connect APs.

Next point to consider is that the interface should be used with relatively "minor" or no changes to the standard to offer WLAN/cellular interworking.

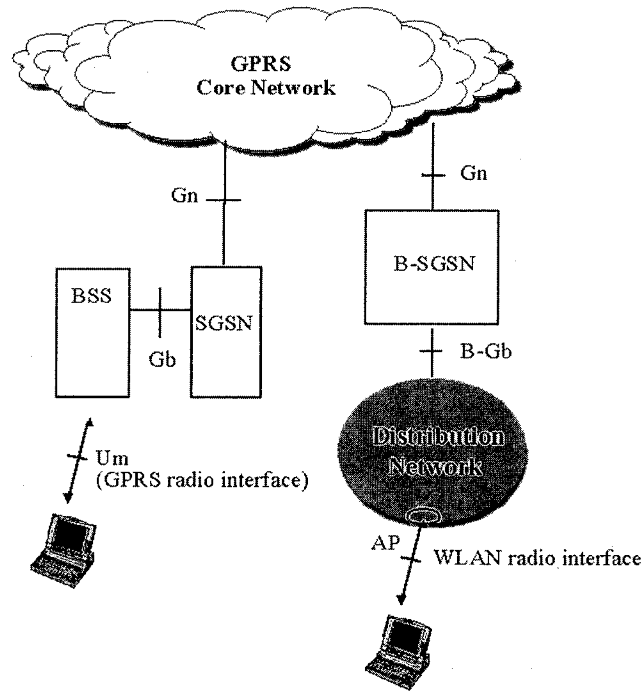

Fig. 12. WLAN/GPRS interworking at Gb interface.

This consideration leaves us with a few options. In case of GPRS it is the Gb interface that divides core network from radio access network. In case of UMTS it is the Iu interface that was actually designed to facilitate two different access networks: satellite and terrestrial.

Once the interface is chosen, the remaining question is at what protocol layer the interworking should be done. The obvious answer limiting the choices is—at a layer that will provide mobility management for roaming between cellular and WLAN RANs. Details are cellular-system dependent and will be dealt with in the following section.

Mobility between cellular RAN and WLAN RAN can be taken care of by the cellular network mobility management. As an alternative, also mobility protocols at user IP level, such as mobile IP (M-IP) render themselves as a viable solution. This approach is quite special in a way since it offers the possibility to bypass the whole cellular core network, at least for the transport of user data traffic. The emergence of mobile IP (M-IP), AAA and IETF security protocols and their support in cellular networks standardization offers a category of interworking scenarios by itself. We will deal with this issue in a separate sub-section.

In the following sub-sections, we will show three classes of possible interworking architectures: reusing GPRS mobility management, reusing UMTS mobility management, and using mobile IP for mobility management.

A. *Interworking Reusing GPRS Mobility Management*

We have already mentioned that the interface that renders itself as most suitable for WLAN/GPRS interworking is Gb, as

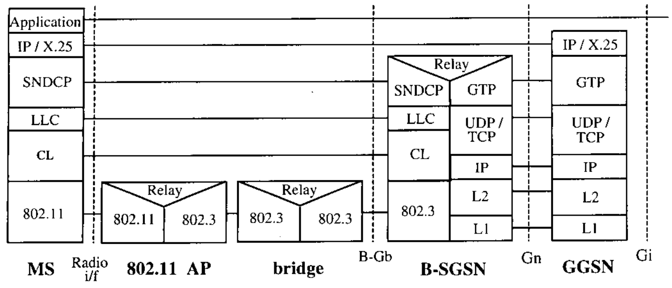

Fig. 13. WLAN/GPRS interworking at Gb interface – protocol stacks.

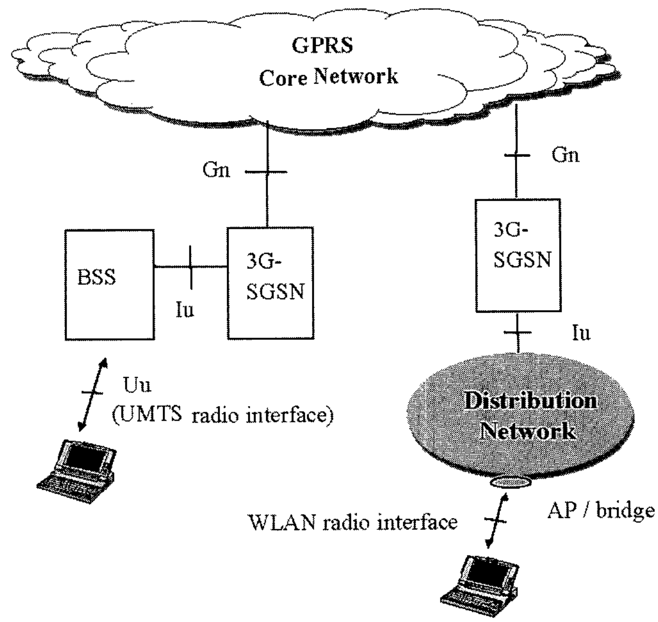

Fig. 14. WLAN/UMTS interworking at Iu interface.

depicted in Fig. 12. Due to the legacy networks and standardized Frame Relay (FR) protocol bottleneck in the Gb interface which has not envisioned very high rate data coming from WLAN access network, we have integrated the interworking function into SGSN and called it broadband SGSN (B-SGSN). Instead of FR we have Ethernet interface on the bottom of broadband Gb (B-Gb).

Now the choice has to be made at what protocol layer we do the interfacing. A look at Fig. 2 reveals that we have to transport mobility and session management protocols (GMM/SM) in the control plane. That would mean that we would have a custom convergence layer (CL) that would take care of mapping GMM/SM and SNDCP PDUs into, say, Ethernet frames. To provide for secure transport, part of the CL layer could be UDP with IPsec. However, LLC protocol takes care of encryption and thus protects both the GPRS signaling and user data. Therefore, reusing this secure layer is probably the easiest way to go. The use of UDP/IP as sublayers of CL could still be useful, e.g., due to the ease of transporting IP PDUs over the WLAN distribution network. We will not elaborate on this issue into more detail but assume that CL maps LLC PDUs into Ethernet (and WLAN) frames. This approach is depicted in Fig. 13.

B. Interworking Reusing UMTS Mobility Management

We have already mentioned that the interface that renders itself as most suitable for WLAN/UMTS interworking is Iu. This scenario is depicted in Fig. 14. We have integrated the interworking function into SGSN in WLAN/GPRS interworking architecture. Here, we have a distinct interworking unit (IWU).

Unlike in GPRS case, in UMTS we have no ciphering over the Iu interface to be reused. In UMTS the MT-RNC path is ciphered. In case ciphering is considered important, Iu can be traversed, e.g., with an IPsec tunnel.

The function of IWU is to terminate RANAP protocol at IWU, transport UMTS signaling that arrives over RANAP and decapsulate user IP PDUs that arrive over GTP tunnel. Fig. 15 shows the protocol stacks.

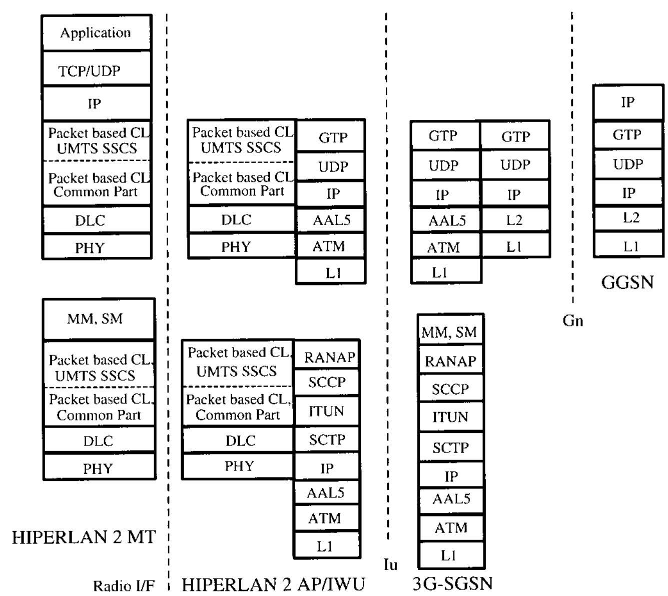

Fig. 15. WLAN/UMTS interworking at Iu interface – protocol stacks.

We have to notice that having a separate IWU does not prevent us from integrating its functionality into 3G-SGSN and have an Ethernet distribution network directly from there, as we had in the GPRS case.

C. Interworking with M-IP

UMTS, as standardized in 3GPP, will offer IP connectivity or access to Internet to mobile users. IP protocol was designed for static users and its addressing scheme and routing is based on location. There is no direct support for mobile users within IP standard. However, there are IP protocol extensions for both IPv4 and IPv6 that allow for mobility of users. Mobile-IP (M-

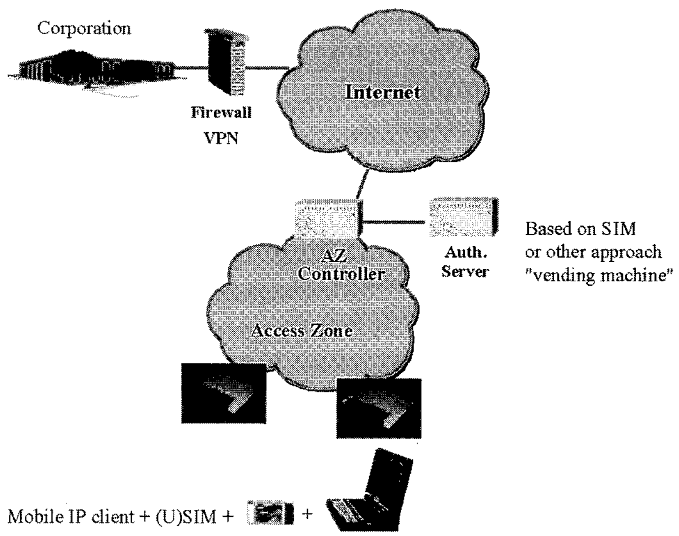

Fig. 16. M-IP mobility – public WLAN access to Internet.

IP) forwards user packets to his/her new destination. Due to the expected pervasive usage of IP over UMTS it is quite appealing to use M-IP also for roaming into alternative radio access networks, such as WLAN. We will not elaborate further on M-IP principles as it has been already described in many places.

Using M-IP as a roaming mechanism, we can see three cases.

Case 1: Roaming between WLAN access zones only.

Home Agent(HA) residing in home network other than cellular, such as ISP or corporate network. User terminal equipment (laptop) connected to a packet cellular mobile terminal and having a WLAN card as well. Then with a co-located foreign agent installed in TE, user would have the freedom of roaming across any IP access networks, including the packet cellular, provided it can gain access to it. WLAN access network and packet cellular network are considered to be two independent networks. Fig. 16 shows the WLAN access part. Zone controller in the figure may contain the functionality of FA as well.

One remaining issue is how to authenticate (and charge) a user roaming into a WLAN access network. The simplest way is to have IP access handled separately from cellular access. User could obtain his/her access password from a local vending machine. User could use authentication based on pre-paid smartcards, or could authenticate using his/her SIM/USIM card from the cellular mobile terminal. The authentication would then be securely tunneled over the Internet to HLR/HSS of a cellular operator. In this scenario, we do not exclude the possibility of a global or large-area ISP operator offering HLR/HSS services as well.

Case 2: Roaming between WLAN access zone and cellular network with M-IP HA residing in home/corporate network.

With a user whose home network offers HA services may roam into WLAN access zone as it was described in Case 1. In case the user has a dual-mode terminal he/she might also roam into UMTS R99 offering HA services (M-IP in UMTS, step 1). In case of GPRS as the cellular domain, probably a co-located FA would be the easiest way of achieving M-IP mobility. For UMTS with M-IP, step 3 architecture this case is shown in Fig. 17. Here we can see that cellular and IP authentication are detached. Cellular authentication is performed over SS7 network and IP authentication over AAA servers with the home network.

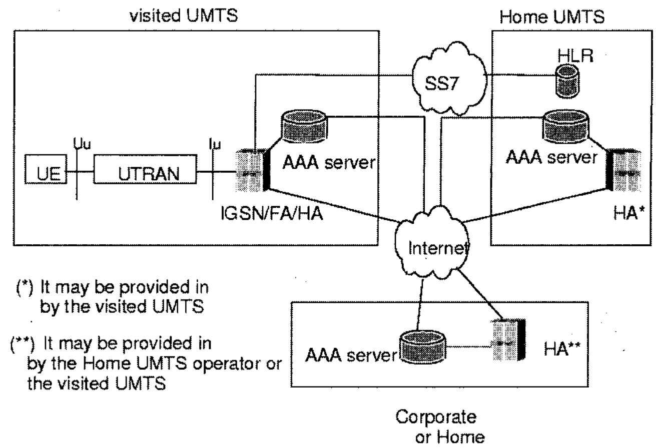

Fig. 17. Mobility with 3GPP-TSG SA WG2 M-IP, step 3 architecture.

Case 3: SIM/USIM authenticated user in both domains.

In this case user uses its SIM/USIM identity to authenticate. In cellular network it is done the standard way. In WLAN access zone authentication information (MAP protocol) is securely tunneled (IPsec) between the Access Zone controller and HSS/HLR. M-IP authentication, although detached from the actual cellular authentication, could also reuse SIM/USIM. This case is illustrated in Fig. 18. Of course, there are other possible authentication mechanisms than GSM/UMTS-based but their functionality would be very similar, plus the key distribution would emerge as a problem.

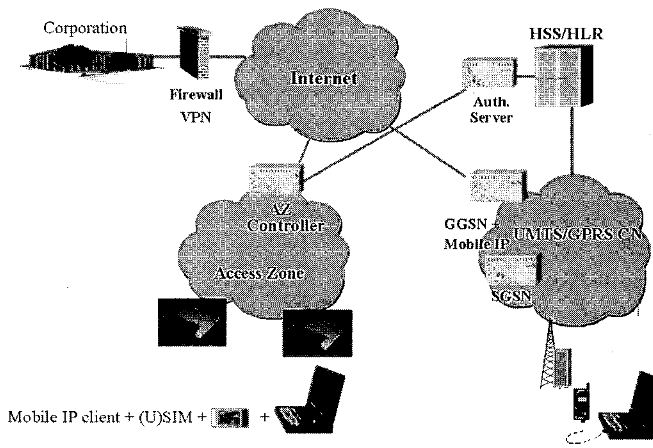

Fig. 18. Interworking with M-IP: (U)SIM authenticated user in both domains.

The most attractive feature of M-IP in interworking is that it is underlying technology independent. From the downside, IP protocol has been designed for transport of non-real-time data and thus transporting real time (RT) traffic, such as streaming video, or even interactive real-time traffic, such as telephone or videophone connection does not come without a penalty. Currently

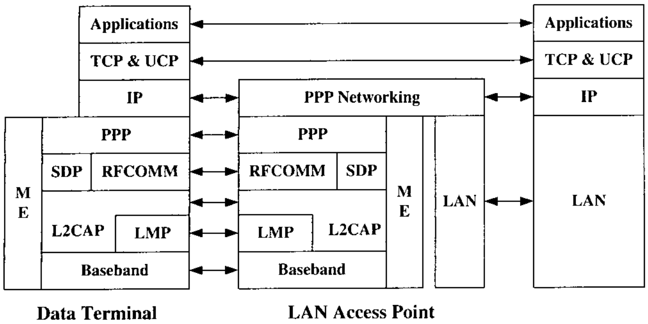

Fig. 19. BLUETOOTH as a LAN access point (PPP).

there is an upsurge of activity at IETF in dealing with issues related to transport of RT traffic or any traffic with QoS requirements attached. However, not enough effort has been spent on combining QoS, mobility and security (encryption and AAA) yet. The combined concept is just evolving and may take some time before it reaches maturity. We see that security and QoS combination are currently being addressed. As for the latency and loss of packets in handover, it might probably be solved with hierarchical M-IP or multicasting packets into old and new points of attachment, assuming users will be capable to perform forward handover, or register with the new point attachment before loosing the old one. We exclude the option of buffering at FA, since a late-arriving IP packet for RT application is lost for the application level.

All the mentioned issues require further study but there is no doubt that they will be solved in the near future because of the immense interest within the networking community.

Interworking over BLUETOOTH

We consider BLUETOOTH as a serious candidate for an alternative interface in cellular/WLAN interworking. Currently, BT is specified only as a serial link and can be used to access LAN over PPP (Fig. 19) using LAN access profile. However, we expect that an IP convergence layer will be specified in the second release or in IEEE 802.15. The default architecture with BT access is M-IP based. If IEEE 802.15 specifies a high rate version of it (20 Mb/s) this will render itself for any before mentioned scenario like any other WLAN interface.

V. CONCLUSIONS

We have presented a brief overview of GPRS and UMTS cellular network standards that are on the evolution path towards IMT-2000. We have also presented a selection of new or upcoming WLAN standards. Several WLAN-cellular network interworking architectures were shown. All of them are feasible solutions each having its strong and weak points. However, if we consider the pace of changes that the cellular (and WLAN) systems standards are going through, it seems that the most stable solution in the long-term would be M-IP-based. This would offer an architecture that is future proof and is in line with the "All-IP" trend in the 3G cellular standardization, not only in 3GPP. Without going deeper into the discussion of IPv6 merits, its use would certainly solve many problems associated with address space exhaustion, security and even route optimization as all these features are in-built into it.

REFERENCES

[1] IMT-2000, Web site at http://www.itu.int/imt.
[2] ETSI, Web site at http://www.etsi.org.
[3] 3GPP, Web site at http://www.3gpp.org.
[4] cdmaOne, Web site at http://www.cdg.org.
[5] M. Mouly and M. -B. Pautet, "The GSM system for mobile communications," *Telecom Pub.*, 1992.
[6] 3GPP, "GPRS system description, Phase 2," 3G TS 23.060.
[7] 3GPP, "Network architecture," 3G TS 23.002.
[8] 3GPP, "UTRAN Iu interface: General aspects and principles," 3G TS 25.410.
[9] Signaling Transport, IETF Working Group, Web site at http://www.ietf.-org/html.charters/sigtran-charter.html.
[10] 3GPP, "Architecture for an All IP network," 3GPP TR 23.922.
[11] 3GPP, "Combined GSM and mobile IP mobility handling in UMTS IP CN," 3GPP TR 23.923.
[12] IEEE, "WLAN Medium Access Control (MAC) and Physical layer (PHY) specifications," IEEE Std. 802.11-1997, Nov. 1997.
[13] ETS 300 652, "Radio Equipment and Systems (RES); HIgh PErformance Radio Local Area Network (HIPERLAN) type 1; Functional specification."
[14] ETSI BRAN TR 101 683, "Broadband Radio Access Networks (BRAN); HIgh PErformance Radio Local Area Networks (HIPERLAN) type 2; System overview," Feb. 2000.
[15] "Broadband Radio Access Networks (BRAN); Cell based convergence layer for HIPERLAN type 2," ETSI BRAN DTS/BRAN-0024003-1.
[16] "Broadband Radio Access Networks (BRAN); HIPERLAN 2 technical specification; Packet based convergence layer," ETSI BRAN DTS/BRAN-0024004-1.
[17] BLUETOOTH SIG, Web site at http://www.bluetooth.com.
[18] IEEE 802.15 Working Group for Wireless Personal Area Networks, Web site at http://grouper.ieee.org/groups/802/15.
[19] S. Lundgren, "HIPERLAN/2 cellular interworking," ETSI BRAN 4TRS081A, Mar. 1998.
[20] CMU Monarch Project, Web site at http://www.monarch.cs.cmu.edu.
[21] Crosspoint Project, Web site at http://www.cs.purdue.edu/research/crossp-oint.html.
[22] Authors' Biographies, Web site at http://daedalus.cs.berkeley.edu.

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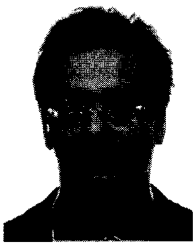

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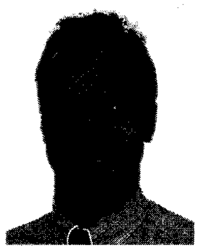

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