

REPORT ITU-R M.2038

Technology trends

(2004)

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1 Introduction

Recommendation ITU-R M.1645 defines the framework and overall objectives of future development of IMT-2000 and systems beyond IMT-2000 for the radio access network. In defining the framework and overall objectives of the future development of IMT-2000 and systems beyond IMT-2000, the significant technology trends need to be considered. This Report provides further information on many of the technology trends concerning radio access network foreseen at the time of preparation of Recommendation ITU-R M.1645. Depending on their development, evolution, expected capabilities and deployment cost, each of these technologies may or may not have an impact or be used for the future development of IMT-2000 and systems beyond IMT-2000. It is expected that the research and future development of IMT-2000 and systems beyond IMT-2000 will consider these technologies and provide guidance on the applicability or influence they might have on the future of IMT-2000 and systems beyond IMT-2000.

Technologies described in this Report are collections of possible technology enablers. There is no decision implied at this stage about whether those technologies will be adopted for future mobile communication systems, and this Report does not preclude the adoption of any other excellent technologies that exist or appear in the future.

2 Scope

This Report provides information on many of the technology trends concerning radio access networks foreseen at the time of preparation of Recommendation ITU-R M.1645.

The Report addresses technology topics that appear relevant to some lesser or greater degree to the future development of IMT-2000 and systems beyond IMT-2000. The Report considers these topics in three broad categories:

- technologies which have an impact on spectrum, its utilization and/or efficiency in this context;
- technologies which relate to access networks and radio interfaces;
- technologies which relate to mobile terminals.

3 Overview of major new technologies

This section presents technology topics that appear relevant to some greater or lesser degree to the future development of IMT-2000 and systems beyond IMT-2000. Technologies having an impact on spectrum, its utilization and/or efficiency; technologies related to access networks and radio interfaces; and technologies related to user terminals are described in § 3.1, 3.2, and 3.3, respectively. Further details are provided in the related Annexes.

The demand for mobile multimedia communications has been rapidly increasing. The radio spectrum is, however, a precious and scarce resource. Therefore, novel technologies for efficient spectrum utilization to enhance the capacity of IMT-2000 and systems beyond IMT-2000 are keenly anticipated. Section 3.1 addresses new radio technologies and their impact on spectrum utilization, including technologies for improving spectrum efficiency, those using multiple antennas such as adaptive antennas and multiple-input multiple-output (MIMO), and those for handling traffic asymmetry and time division duplex (TDD).

Advanced radio resource management (RRM) algorithms and flexible frequency sharing methods are beneficial in maximizing and optimizing the frequency resource utilization. In addition, antenna and coding technologies such as smart antennas, diversity techniques, coding techniques, space-time coding, and combined technologies improve the radio link quality in multipath Rayleigh fading channels. Furthermore, efficient multiple access schemes and adaptive modulation improve the bandwidth efficiency of the systems.

Adaptive antennas improve the spectral efficiency of a radio channel, and in so doing, greatly increase the capacity and coverage of most radio transmission networks. This technology uses multiple antennas, digital processing techniques, and complex algorithms to modify the transmitted and received signals at a base station and at a user terminal. In addition, MIMO techniques can provide significant improvements in the radio-link capacity by making positive use of the complex multipath propagation channels found in certain terrestrial mobile communications. MIMO techniques are based on establishing several parallel independent communication channels through the same space and frequency channel by using multiple antenna elements at both ends of the link.

In broadband multimedia communications, asymmetric traffic is envisaged to be dominant. Due to uncertainties in future traffic asymmetry, future mobile communication systems should be adaptable to different ratios of asymmetry especially at the personal-area and the user-access levels in order to deliver the offered traffic asymmetry while simultaneously maintaining high spectrum efficiency. TDD is one of the techniques suitable to support asymmetric high data rate services while providing flexible network deployment including busy urban hotspot and indoor environments as well as wide area applications. TDD systems do not require a duplex frequency pair since both the uplink and downlink transmissions are on the same carrier within the same spectrum band. In future mobile

communication systems, flexibility and integration/convergence will be key factors. In section 3.2, technologies related to IP applications and IP broadband wireless access, those related to software-defined radio (SDR), and those achieving wider coverage such as radio on fibre (RoF), multi-hop radio networks, and high altitude platform station (HAPS) are presented.

Many wireless communication systems provide users with convenient ways to access the Internet and to communicate with one another or access multimedia content. Wireless technologies are expected to progress in a direction that will allow native support of multimedia and Internet services. The technological implication of the integration of IP and wireless is more prominent in the case of mobile broadband Internet access. To support real-time or multimedia applications using end-to-end IP, all the elements, in general, of a service path must support the requirements of mobile or broadband wireless access. To support efficient IP transport over a broadband mobile environment, we essentially need a set of diverse technologies grouped around the concepts of “seamless”, “broadband” and “energy-efficient”.

SDR provides reconfigurable mobile communications systems that aim at providing a common platform to run software that addresses reconfigurable radio protocol stacks thereby increasing network and terminal capabilities and versatility through software modifications (downloads). Basically, SDR concerns all communication layers (from the physical layer to the application layer) of the radio interface and has an impact on both the user terminal and network side.

Radio on fibre is defined as a system that enables the transparent interconnection of a base station, or equivalent wireless system radio interface network element, to its associated transmission and reception antennas by means of an optical network. Optical fibre presents very low insertion loss to achieve long cable spans of up to several kilometres and an enormous bandwidth to transport many different RF signals over a single fibre.

Multi-hop wireless access technology utilizes multiple serial wireless connections between the target user terminal and a base station in a homogeneous system or across different systems. In a wireless system with higher frequency bands where a smaller coverage area is available, multi-hop wireless access technology may be a solution for user terminals to gain wireless connectivity to a base station.

Another solution is applying HAPS, which is a new technology based on a flying platform. The HAPS system can provide mobile cellular coverage and fixed wireless services to several regions ranging from a high-density (urban) area to low-density (rural) areas.

Flexibility and integration/convergence are also key factors for user terminals. Section 3.3 addresses technologies for achieving reconfigurable user terminals such as terminal architecture, reconfigurable processors, RF micro-electro-mechanical systems (MEMS) for achieving smaller user terminals, and user interfaces for a flexible user terminal.

Future mobile user equipment may assume characteristics of general-purpose programmable platforms by containing high-power general-purpose processors and provide a flexible, programmable platform that can be applied to an ever-increasing variety of uses. The convergence of wireless connectivity and a general-purpose programmable platform might heighten some existing concerns and raise new ones; thus, environmental factors as well as traditional technology and market drivers influence the architecture of these devices. A well-designed embedded processor with a reconfigurable unit may enable user-defined instructions being efficiently executed, since general-purpose processors such as CPUs or DSPs are not suitable for bit-level operation. This type of processor, which can handle many kinds of bit-level data processes, can be applied to various applications for mobile communication systems with efficient operation.

RF MEMS are integrated micro-devices (or systems) combining electronic and mechanical components fabricated using an integrated circuit (IC) compatible batch-processing technique. This technology can yield compact, light weight, low power, and high performance ICs to replace discrete passive RF components such as VCO, IF, RF filters, and duplexers.

Wearable computing is also a promising technology that will give birth to new ideas of man-machine interfaces applicable to user terminals. So far, many solutions are not standardized but are proprietary methods. There is also a clear need for harmonization and for open use of common open interface standards.

3.1 New radio technologies and impact on spectrum

3.1.1 Technologies for improving bandwidth efficiency

To meet the strong demand for broadband multimedia services to both nomadic and mobile users, it is necessary to increase the maximum information bit rate of systems beyond IMT-2000. To enhance the capacity of IMT-2000 and systems beyond IMT-2000, novel technologies or new concepts for improving bandwidth efficiency are indispensable. Advanced radio resource management (RRM) algorithms will be beneficial for maximizing the resource utilization. In addition, antenna and coding technologies such as smart antenna, diversity techniques, coding techniques, space time coding, and combined technologies will be necessary for systems beyond IMT-2000 to improve the wireless link quality under multipath Rayleigh fading channels. Furthermore, efficient multiple access schemes, adaptive modulation, adaptive downlink modulation, and multi-hopping technology will be needed to improve the bandwidth efficiency of the system.

Technologies for improving bandwidth efficiency which are discussed in this Recommendation include:

- bunched systems;
- ultra-wideband (UWB);
- adaptive modulation and coding (AMC);
- flexible frequency sharing;

High level descriptions of the above technologies are to be found in the following sections, whilst more detailed information is provided in Annex 1.

3.1.1.1 Summary of the technology

- *Bunched systems:* In pedestrian and indoor environments, there will be severe fluctuations in traffic demands, high user mobility and different traffic types. This highly complex environment will require advanced RRM algorithms. It could be beneficial to have a central intelligent unit that can maximize the resource utilization. This capability is provided by bunched systems.
- *WWB:* The basic concept of UWB is to develop, transmit and receive an extremely short duration burst of RF energy. The resultant waveforms are extremely broadband (typically some gigahertz).
- *AMC:* Adaptive modulation and coding schemes adapt to channel variation by varying parameters such as modulation order and code rate based on channel status information (CSI).
- *Flexible frequency sharing:* Sharing of frequency carriers between different operators is a method to optimize the use of spectrum resources.

3.1.1.2 Advantages

- *Bunched systems:* Bunched systems provide dynamic load distribution, dynamic RRM, and adaptive coverage control. Bunched systems are well suited to hotspot coverage.
- *UWB:* UWB systems provide the potential for spectrum sharing between services and more efficient use of spectrum.
- *AMC:* The advantage of AMC schemes is that the amount of spectrum utilized is based on the actual channel conditions rather than worst case channel conditions.
- *Flexible frequency sharing:* More efficient use of the spectrum resource.

3.1.1.3 Issues to be considered

- *Bunched systems:* Design issues of the radio access network (RAN) and the RRM algorithm for the bunched systems must be considered.
- *UWB:* No internationally agreed definition of UWB exists because the applications and uses to which the technology may be applied are very diverse and the devices have not been fully developed. The regulatory and interference impacts of UWB are not yet known.
- *AMC:* Delays in reporting channel conditions reduces the reliability of the channel status indicator which may cause the system to select incorrect modulation levels and coding rate.
- *Flexible frequency sharing:* The use of flexible spectrum sharing may have serious implications on the time required to scan the spectrum and locate a radio access technology (RAT) carrier after the terminal has been powered on.

3.1.2 Technology solutions to support traffic asymmetry

3.1.2.1 Background

Radio interfaces for IMT-2000 systems and systems beyond IMT-2000 may support different capabilities in the uplink and downlink with respect to traffic asymmetry. In this context asymmetry means that the basic amount of traffic and consequently the amount of needed resources may differ between the uplink and the downlink direction.

There are at least four aspects of traffic asymmetry:

- *At the personal area level:* the degree of asymmetry for traffic between devices of a personal area network (PAN).
- *At the user access level:* the degree of asymmetry for the traffic between a specific user and the network for a specific service.
- *At the cell level:* the degree of total traffic asymmetry in a specific cell.
- *At the network level:* the degree of total traffic asymmetry in the entire network.

These views differ in particular concerning the considered amount of traffic and the speed of change of the asymmetry. For individual users (i.e. at the personal area level and user access level) the degree of asymmetry may change quickly. But the degree of total asymmetry over a cell (i.e. at the cell level) and even more over the entire network (i.e. at the network level), will change much slower due to aggregation of individual services on one hand and changing mix of services on the other hand. It depends on the system design whether and how this offered changing traffic asymmetry can be delivered efficiently.

3.1.2.2 Service mix in IMT-2000 systems

In IMT-2000 networks or systems beyond IMT-2000, there will be a mix of symmetric applications as well as predominately downstream (downstream direction is from base station to mobile station(s))¹ or predominately upstream (upstream direction is from mobile station(s) to base station)¹ applications using different data rates. The most recent estimates for a mix of traffic are described in Report ITU-R M.2023. An analysis of these estimates indicates that the total traffic asymmetry in a specific cell or the entire network from IMT-2000 users would have the same “down load” characteristics as in the fixed network, i.e. it is predominately downstream. However, it should be noted that the traffic characteristics and the degree of traffic asymmetry between a specific user and the network for some IMT-2000 specific services may be different. It is expected that new applications, such as picture and video clips, as well as peer-to-peer traffic, which would generate traffic from terminals or servers connected over wireless, will affect the IMT-2000 traffic mix. Due to uncertainties of the future traffic asymmetry, future radio access systems should be adaptable to different ratios of asymmetry especially at the personal area level and at the user access level to deliver the offered traffic asymmetry by maintaining at the same time high spectrum efficiency.

¹ Per Recommendation ITU-R F.1399 – Vocabulary of terms for wireless access.

3.1.2.3 Technical aspects

Radio interface support for asymmetric traffic can be achieved by different means:

- By asymmetric resource allocation, e.g. asymmetric frequency allocation in case of frequency division duplex (FDD) operation or asymmetric time-slot allocation in case of TDD operation.
- By symmetric uplink/downlink frequency allocation in the case of FDD or symmetric uplink/downlink time-slot allocation in the case of TDD with only partial use of the available capacity in one of the two directions.
- By applying different capacity-enhancing technologies to uplink and downlink, regardless of the resource allocation. These technologies are typically independent of the duplex scheme.

More details are given in Annex 2.

3.1.3 Advanced system innovation using TDD

TDD is well suited for asymmetric high data rate services while providing flexible low cost network deployment including busy urban, hotspot and busy indoor environments as well as wide area applications. TDD is a technique where both the uplink and downlink transmissions are on the same carrier within the same spectrum band. This means TDD technology can operate within an unpaired frequency band; i.e. no duplex frequency pair is necessary. The minimum spectrum requirement is only half the bandwidth of the FDD mode, i.e. only one 5 MHz spectrum allocation is necessary when the wideband code-division multiple access (W-CDMA) TDD (IMT-2000 CDMA TDD) chip rate is operating at the same 3.84 Mcchip/s harmonized chip rate as the W-CDMA FDD (IMT-2000 CDMA Direct Spread) mode.

Currently, within IMT-2000, TDD makes use of both CDMA and time division multiple access (TDMA) techniques to separate the various communication channels by both time slot and CDMA code. Time slots can be assigned to carry either downlink or uplink channels. The TDMA structure also permits the use of a specific algorithm by which multiple channels are jointly recognized and decoded (joint detection algorithm). This method eliminates intracell interference almost completely and helps increase system capacity. This is feasible in TDD because the transmission and reception occur at the same frequency and exhibit similar channel distortions, thus simplifying processing.

Due to the TDMA structure and the joint detection algorithm, which significantly reduces interference from other CDMA signals present in the time slot, W-CDMA TDD behaves much like a TDMA system. It does not suffer from cell breathing and the necessity to maintain sufficient operating margin to compensate for the uncertainty, nor does it require a soft hand-off capability. This is of particular value for hotspot scenarios with heavy data load and small cell sizes such as indoor and outdoor (pico- and microcells). Since time slots for uplink and downlink can be assigned separately, W-CDMA TDD is particularly suited for asymmetric traffic. The degree of asymmetry can be dynamically controlled, improving overall operating efficiency.

From the beginning, the TDD standard has been designed in anticipation of the implementation of smart antennas which can substantially improve the system capacity. Smart antennas give particular advantages in macro- and microcell scenarios where the user signals are not very scattered. Again, TDDs use of the same physical radio channel for both the uplink and downlink simplifies the processing required to shape the antenna beams. This unique characteristic, channel reciprocity, of TDD also makes it practical to implement advanced diversity and coding techniques.

Finally, TDD is cost-efficient for network deployments as it leverages the infrastructure of an FDD-only roll-out by providing scalable capacity for “hotspots”. This is accomplished through a multi-tier architecture of FDD and TDD macro-, micro- and picocells.

3.1.4 Adaptive antenna concepts and key technical characteristics

3.1.4.1 Introduction, and benefits of adaptive antennas in IMT-2000

Formally, adaptive antennas may be defined² as “an array of antennas which is able to change its antenna pattern dynamically to adjust to noise, interference and multipath. Adaptive antennas are used to enhance received signals and may also be used to form beams for transmission”.

Likewise, switched beam systems “use a number of fixed beams at an antenna site. The receiver selects the beam that provides the greatest signal enhancement and interference reduction. Switched beam systems may not offer the degree of performance improvement offered by adaptive systems, but they are much less complex and are easier to retrofit to existing wireless technologies”.

Finally smart antennas are similarly defined by the same source as systems that “can include both adaptive antenna and switched beam technologies”.

The reader is cautioned that there is some variation in terminologies used here; for example, non-adaptive or non-switched systems are sometimes termed smart simply due to the incorporation of masthead RF electronics, and unfortunately often the terms adaptive and beam-forming are used rather loosely.

3.1.4.2 Benefits of integrating adaptive antennas

Benefits of adaptive antennas in IMT-2000 networks

Adaptive antennas improve the spectral efficiency of a radio channel, and in so doing, greatly increase the capacity and coverage of most radio transmission networks. This technology uses multiple antennas, digital processing techniques and complex algorithms to modify the transmit and receive signals at the base station and at the user terminal. Systems in all of the existing IMT-2000 radio interfaces could enjoy significant performance improvements from the application of adaptive antenna technology.

Further improvements by including adaptive antennas in the initial design concept

While applying adaptive antenna technology to an existing radio interface can significantly improve the spectral efficiency of that radio interface, there are more significant efficiency benefits that might be derived if adaptive antenna technology is incorporated into the design of the radio

² LIBERTI and RAPPAPORT *Smart Antennas for Wireless Communications* [1999] Wiley.

interface from the outset. Many aspects of an air interface design affect the spectral efficiency gains that can be realized from the adaptive antenna technology including the following:

- duplexing methods;
- carrier bandwidth;
- modulation methods;
- signalling control: broadcast and paging methods;
- burst and frame structures;
- media access control methods.

The result of this approach can be quite significant. It can be shown that integrating adaptive antennas into the initial design concept can yield spectral efficiency increases of $> 4000\%$ over existing 2G systems and $> 400\%$ increases over the new IMT-2000 radio interfaces.

3.1.4.3 Summary

There are a number of less commonly appreciated adaptive antenna technology advantages. For example, the inevitable redistribution of RF power amplification elements for adaptive antenna systems commonly leads to lower total amplifier cost than is likely to be the case with conventional technology. From a deployment viewpoint it is sometimes attractive to utilize adaptive antenna stations in only a proportion of the overall infrastructure in an area, and similarly the interference mitigation advantages may be particularly beneficial for such situations as cross-border coordination arrangements.

Integrating adaptive antenna systems into the design of future IMT-2000 systems and systems beyond IMT-2000, will significantly improve the spectral efficiency of these new radio systems. Spectral efficiency gains from adaptive antenna systems can be used not only to reduce the number of base stations (cells) needed to deploy an IMT-2000 network, but also to obtain significantly increased data rates within a limited amount of increasingly scarce spectrum.

3.1.5 Multiple-input multiple-output techniques

3.1.5.1 Summary of the technology

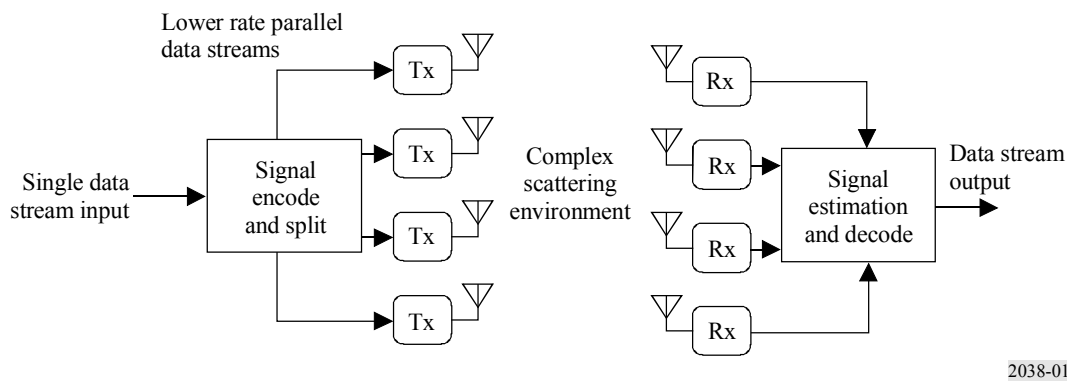
MIMO techniques can provide significant improvements in the capacity of the radio link by making a very positive use of the complex multipath propagation channels found in terrestrial mobile communications. There are many alternative solutions within this family of techniques, but they are all based on establishing several parallel independent communication channels through the same space and frequency channel by using multiple antenna elements at both ends of the link.

3.1.5.2 Advantages

The advantage of exploiting MIMO techniques is to increase the system throughput data rate for the same total radiated power and channel bandwidth.

In highly scattering propagation environments, the theoretical maximum data rate for MIMO algorithms increases directly in proportion to the number of antennas, rather than only being proportional to the logarithm of the number of antennas when conventional phased array beam forming methods are used. For the arrangement shown in Fig. 1 the MIMO method has a potential gain of double capacity over using conventional phased array algorithms in cellular networks.

FIGURE 1

MIMO transmitter-receiver concept**3.1.5.3 Issues to be considered**

How much of these theoretical gains can be achieved in realistic deployment scenarios is the subject of ongoing research within the industry, with particular emphasis on maximizing the performance of the terminal antenna system within the restricted form factors of future terminals such as laptops, personal digital assistant PDAs and handsets, and also in minimizing the computational complexity of the signal processing algorithms.

Initial results reported in the literature have shown that most of the theoretical MIMO capacity could be exploited with appropriate terminal antenna array design. In these the antenna elements can be separated by less than a wavelength and can also make use of alternative polarization to increase the number of elements within a given size terminal. It has been demonstrated that even four elements within a terminal can give significant gains in capacity when mounted within the outline of a typical PDA.

However, for all aspects of MIMO system design a thorough characterization of the MIMO propagation channel in realistic deployment scenarios is needed and this is the subject of study in the 3GPPs and COST 259 and COST 273 research projects.

A brief review of MIMO techniques is provided in Annex 5, along with a list of references to some of the more important published work in this field.

3.2 Access network and radio interfaces**3.2.1 Software defined radios (SDRs)****3.2.1.1 General**

SDR is a technology to provide reconfigurable mobile communication systems, which aim at providing a common platform for running software addressing reconfigurable radio protocol stack thereby increasing network and terminal capability and versatility by software modifications (downloads). With the proliferation of open application programming interfaces (APIs), software from different vendors can run on proprietary hardware platforms. On such platforms, the air interface protocols and applications are executed under the control of a common software environment.

SDR concerns therefore basically all communication layers (from the physical layer to the application layer) of the radio interface (see Fig. 19) and impacts both mobile terminal and the network side.

As key objectives, SDR shall provide means for:

- adaptation of the radio interface to varying deployment environments/radio interface standards;
- provision of possibly new applications and services;
- software updates;
- enabling full exploitation of flexible heterogeneous radio networks services.

In Annex 6 we provide more details on architecture for reconfigurable terminals and supporting networks.

3.2.1.2 General requirements for SDR

The provision of SDR poses requirements on the mobile communication system, which fall into three distinct groups:

- radio reconfiguration control;
- creation and provisioning of services over converging networks and different radio access modes;
- user environment management.

Moreover SDR has to consider and take into account appropriate security functions that allow reliable operation and avoid any potential abuse despite the high flexibility provided by SDR.

3.2.1.3 Logical SDR-architecture

The logical SDR-architecture has to support the following functions:

- management of terminal, user and service profiles in the network entities and the terminal;
- efficient download control and reconfiguration management for terminals and network entities;
- negotiation and adaptation functionalities for services and RATs (e.g. vertical handover);
- assurance of standard compliance.

These functions are logical functions, i.e. they can be implemented in different places in the network. Moreover they can be distributed within the network and between network and terminal.

An example of such a logical SDR-architecture (terminal and network aspects) is given in Annex 6.

3.2.1.4 Constraining considerations

SDR, due to its huge flexibility and due to the possibilities to change nearly all parameters of the radio interface or higher layer parameters (e.g. parameters in the transport layer) are potential subject to standardization, if mixed operations (mix of different hardware and software vendors) and open APIs between modules are required.

Related topics to be considered are for example:

- security functions for reliable and trusted software download (e.g. software download limited to manufacturer approved builds available only from a manufacturer's secure server to protect manufacturer's regulatory liability for system integrity);
- for the terminal: separation of functionalities used for applications and for radio-specific software;
- for the terminal concerning new applications and services: request user confirmation before software update to avoid incompatibility with other already installed software.

3.2.2 High data rate packet nodes (HDRPN)

Since packet data services display different characteristics than voice data services it may be possible to take advantage of the characteristics of certain packet data applications to enhance the performance of the system when it accommodates these services. One such change in architecture and structure that takes advantage of the more tolerant delay characteristics of certain classes of packet traffic is the HDRPN concept. This concept places nodes, HDRPN, close to routes that mobile subscribers are expected to traverse and when the subscribers are in close proximity to these nodes the system transfers large files at high data rates to users that have large files waiting for them. The HDRPN do not transmit sufficient power to allow the mobile terminals to receive high data rates when they are not in the proximity of one of the high rate packet nodes. This will translate into less interference across the region and may result in fewer base stations.

Future IMT-2000 systems are expected to provide high data rate packet services, see new questions, that will seriously test the practical limits of existing technology. It is anticipated that this type of packet link is likely to be asymmetrical with the downlink transfer frequently operating at a much higher data rate. Often the data is not sensitive to short delays and as much as a minute delay may be acceptable. This set of requirements are different than the original requirements for IMT-2000 which strongly emphasized voice requirements and balanced transmission paths. In the next phases of IMT-2000 it is essential for us to re-examine the basic architecture to determine if these new requirements might affect the structure of the system. In some of the new applications it will be practical to negotiate a reasonable delay value in other cases a best effort capability will suffice. Internet users have become used to a best effort category of service when they have used line modems for access. If a large file takes a minute to transfer at a rate of 144 kbit/s. The same file can be transferred in six seconds at 1 444 kbit/s. Therefore, if the delay to start the transfer is 54 s in the later case the transfer is still completed at the same time as the first case.

Mobile terminals in vehicles are generally moving quite rapidly and are, therefore, quickly changing their relationship to base stations. This is particularly true for automobiles on expressways and high-speed trains. Therefore, since the class of data described above can tolerate short delays it is logical for the highly mobile terminals to receive larger files at a high data rate when they are close to a high rate packet node. This ultimately reduces the cost of terminals/base stations and can significantly reduce the interference for other terminals/base stations. The mobile terminals can receive lower rate data over the entire region.

3.2.3 Internet technologies and support of IP applications over mobile systems

3.2.3.1 Summary of the technology

The Internet technologies and wireless technologies have to move in a direction to accommodate each other more natively. The technological implication of the integration of IP and wireless is more prominent in the case of mobile broadband access of Internet. In order to support real-time or multimedia applications using end-to-end IP, all the elements, in general, of a service path, it is necessary to support the requirements of mobile or broadband wireless access. Similarly, access networks should be equipped to support high-speed IP mobility while maintaining negotiated quality of service (QoS). For example, mobile network components should be able to monitor and evaluate the wireless channel conditions, and adjust transmission parameters accordingly to avoid severe degradation of throughput.

For supporting efficient IP transport over mobile environment, we essentially need a set of diverse technologies grouped around the keywords, “seamless”, “broadband” and “energy-efficient”. From these we can derive many Internet-related technologies, for example, QoS, routing and handoff, location management, QoS management, wireless resource management, paging/signalling protocols, terminal architecture, operating system support, adaptive system reconfiguration, etc.

In view of support of IP applications the following applications can be mentioned for example.

Less QoS-demanding services like web access, email or SMS are already being provided over current cellular systems. Among other potential and challenging IP-based applications over mobile systems, VoIP is the front-runner, currently being implemented in increasingly smaller devices, from notebook PCs to PDAs. However, issues like high bandwidth requirement, handover delay, etc. will hinder its deployment unless significant improvement is not made, for example, through efficient header compression or seamless handover by access points.

Mobile commerce/banking services are other lucrative applications where the potential of integration of Internet and mobile technologies can be exploited. In such services, specifically and in all other services in general, a reliable (continuous, non-breaking) and secure wireless environment is a prerequisite. The solution may come through improved wireless technology or Internet technology or both. A security framework to support IP applications over mobile systems is required.

3.2.3.2 Advantage of the technology

If the current trend of mobile usage continues, the integration with Internet technologies will bring about a revolution in the wireless communications industry that will affect vendors, service/application/context providers, policy makers, and users.

Current wireless systems are (and probably future systems will also be) independently designed, implemented and operated to meet different requirements on mobility, data rates, services, etc. Some, if not all, of these systems can simultaneously provide services at a specific geographic location, creating a heterogeneous wireless environment for users in overlaid service areas. Also, next generation wireless networks would be heterogeneous networks that support multiple broadband wireless access technologies and global roaming across systems constructed by individual access technologies. For the seamless integration of heterogeneous wireless systems, all-IP solution appears to be most promising.

3.2.3.3 Issues to be considered

Beginning with the network architecture there are several important issues that should be considered to realize an efficient mobile Internet environment as well as heterogeneous wireless networks. To build a sustainable system we must address issues related to security and scalability. Also, interoperability with legacy and future systems, IP addressing, IPR issues, etc., have to be considered.

3.2.4 IP broadband wireless access

For the foreseeable future, data services are and will be carried predominantly on IP networks. The overall network architecture therefore should evolve to an end-to-end architecture that, at layer 3, is a pure IP architecture. Such an architecture will enable transparent access from mobile devices to all data applications that are accessible via the Internet and corporate intranets. Provided that there is adequate system capacity and user data rates, this approach will allow the wireless data market to grow organically at the same rate as the explosive growth of e-commerce and “infotainment”, which services are currently assumed to be wireline in nature. This approach also eliminates the need for duplicate programming and/or repackaging of content, i.e. only one version for both Internet/intranet and wireless applications. To allow this to happen, a network architecture needs to evolve that brings IP transparency to the network edge and utilizes IP protocols. The required network architecture is illustrated in Fig. 2, and the ramifications for the protocol stacks are shown for one embodiment in Fig. 3.

FIGURE 2
Example of a pure-IP access network architecture

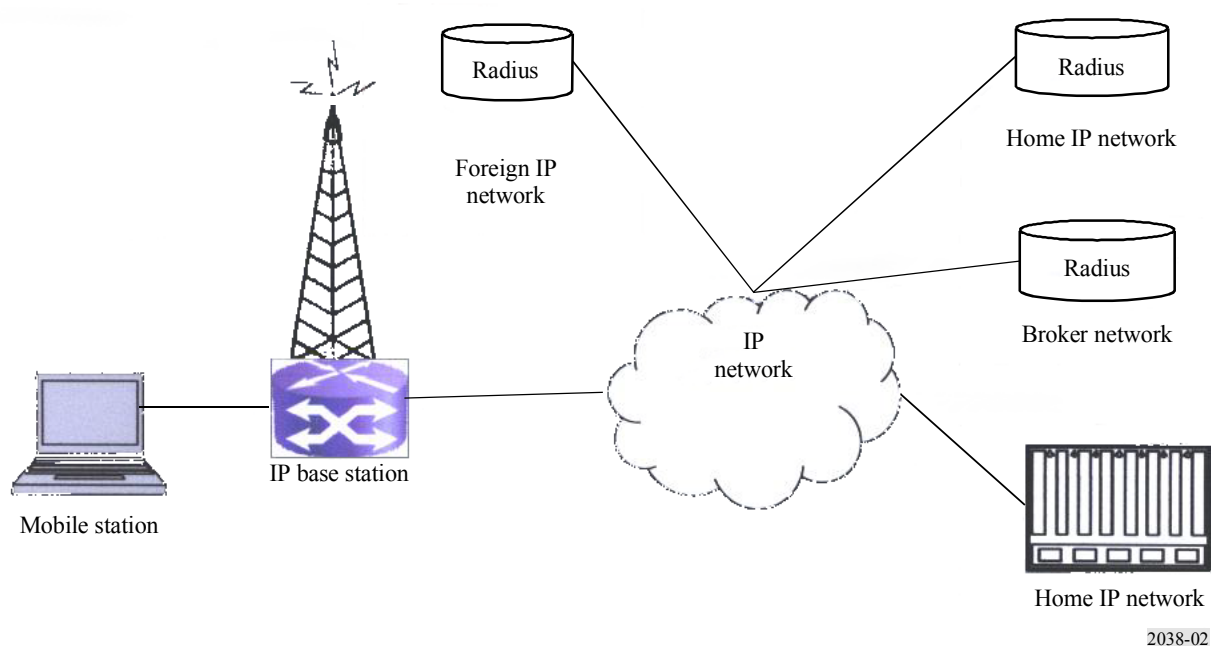
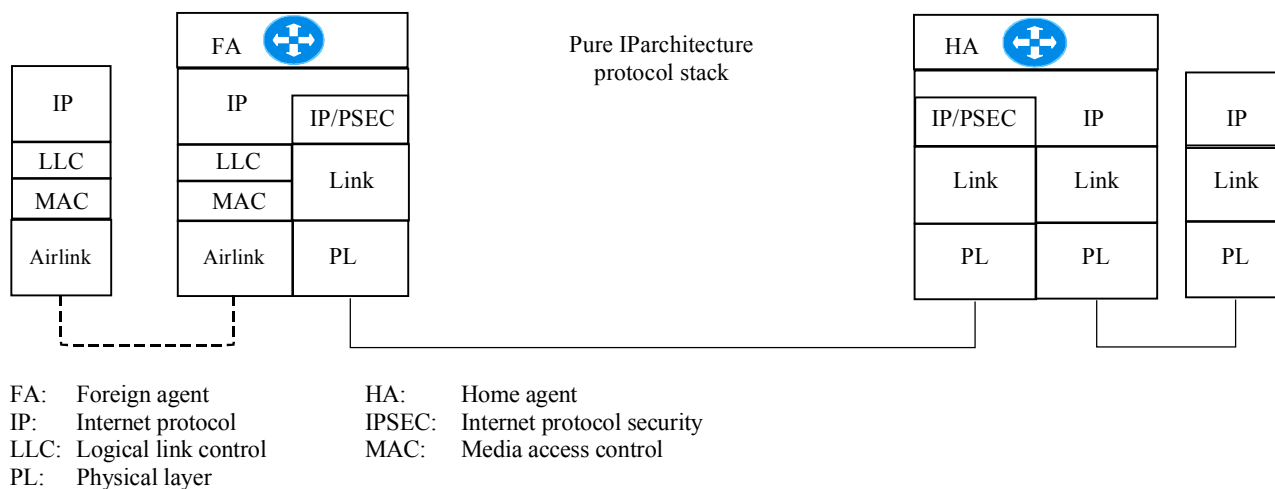


FIGURE 3
Example of a pure-IP access network protocol stack



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Examples of protocols required:

- 1 *Mobile IP* – To support mobility. Additional enhancements need to be worked to allow seamless roaming at vehicular speeds.
- 2 *Radius and AAA* (authentication, authorization, accounting)– For support of security features and accounting.
- 3 *SIP* – For support of end-to-end service control.

To allow optimal end-to-end performance the wireless access networks itself also needs to be IP-aware. Current wireless access networks also assume that the predominant data traffic is highly asymmetrical, the typical model being web-surfing. Though this is true in many cases, more symmetrical data traffic applications are rapidly emerging. Such applications include videoconferencing and various enterprise data applications.

3.2.4.1 Summary of the technology

Table 1 shows the distinguishing characteristics between existing 3G interfaces and the emphasis of an IP access network. Work on such a mobile broadband wireless access network is currently ongoing in IEEE 802.20.

3.2.5 Radio on fibre (RoF)

3.2.5.1 Summary of the technology

In this Report, radio on fibre (RoF) is defined as a system which enables the transparent interconnection of a base station, or equivalent wireless system radio interface network element, with its associated transmission and receiving antennas by means of an optical network. The signals propagating through the optical network are a replica of the signals at the base transmitter station (BTS) radio interface.

The definition can be generalized to include in it not one, but several BTS repeaters, as long as all of them are housed in the same room and share one common basic infrastructure, i.e., power, air conditioning, etc.

Such RoF systems are described in Annex 10.

TABLE 1

Subject	Broadband IP access network	3G
End-user	Fully mobile, high throughput data user Asymmetric or symmetric data services End-user devices initially PC card enabled data devices Full support of low-latency data services	Voice user requiring data services Highly asymmetric data services End-user devices initially data enabled handsets Support for low latency services still an issue
Service provider	Wireless data service provider – Greenfield start or evolving cellular carrier Global mobility and roaming support	Cellular voice service provider evolving to data support Global mobility and roaming support
Technology	New PHY and MAC optimized for packet data and adaptive antennas Licensed bands below 3.5 GHz Packet oriented architecture Channelization and control for mobile multimedia services. Mobile-IP based High efficiency data uplinks and downlinks Low latency data architecture	See Recommendation ITU-R M.1457 Licensed bands below 2.7 GHz Circuit oriented architecture – evolving to packet on the downlink Channelization and control optimized for mobile voice services. MAP/SS7 based Medium efficiency data downlinks, low efficiency uplinks Latency still an issue

3.2.5.2 Advantages of the technology

RoF systems are applicable when the distance between BTS and antennas is so large that it becomes impractical to connect them through coax cable, even with the use of in-line repeaters. Optical fibre presents very low insertion losses, which allows unrepeated fibre cable spans of up to several kilometres, and enormous bandwidth: many different RF signals can be transported over one single fibre. RoF systems use simple analogue modulation of lightwave signals without modulation and demodulation of the RF signal. The RF signal channels can be inserted or extracted by straightforward optoelectronic circuitry. RoF is also immune to electromagnetic interference and grounding problems; the fibre cross-section is very low, which allows several tens of fibres to be bundled in one single optical cable; optical cable is rugged, it can be placed in ducts, hung on poles or directly buried; with a small extra cost it can even be lined with a rodent protective steel cover.

In microcellular scenarios where different wireless systems are co-sited, RoF enables the use of centralized processing, i.e., the system RF heads are placed in close proximity to the antennas, and

the wireless systems processing equipment is housed in a centralized room, usually under controlled environmental conditions. Depending on the deployment scenarios, centralized processing might bring the following benefits. It allows a dense deployment of repeaters in urban environments, diminishes the number of required building rooftop housing installations, lowers the need for costly high-power RF amplifiers, and improves the spatial distribution of BTS capacity.

These benefits, though applicable to all wireless systems, are especially significant in IMT-2000 – and beyond – cellular networks for the following reasons:

- IMT-2000 frequency bands are higher than those assigned to 2G. Similarly, it is reasonable to expect that IMT-2000 systems beyond frequency bands will be higher than those assigned to 2G, with correspondingly higher propagation losses. This would make it more difficult to provide adequate coverage with macrocells only, so IMT-2000 and systems beyond would favour more comprehensive microcell deployment.
- Because of their higher capacity compared to 2G, IMT-2000 and systems beyond may require a larger number of cells to cover a given geographical area. Since it is becoming increasingly difficult to commission new sites, solutions like RoF allow BTS equipment concentration to simplify radio network rollout.
- Compared to 2G systems, the capacity of an IMT-2000 and systems beyond carrier is quite large. This favours radio coverage solutions, like RoF, which allow tailoring the spatial radio distribution of the carrier capacity to the specific coverage area, or coverage volume, requirements.

3.2.5.3 Issues to be considered

When an RoF system is used to radiate the same carrier, or carriers, from different antennas, the handover among the cells under the same BTS is not required. However, some interference may occur in the overlapping area between cells because of the multipath routing through different antennas.

When such an RoF system has antennas widely spaced apart from the BTS, the spatial accuracy of any location system based on the wireless system cannot be better than the distance between the antenna and BTS. This might lower the precision of an IMT-2000 based location system, whose accuracy can be few tens of metres if it uses differential time of arrival procedures to determine mobile terminals relative position to different BTS.

Furthermore, key devices such as the optical modulator and low noise amplifier would be developed later.

3.2.6 Multi-hop radio networks

3.2.6.1 Summary

Multi-hop radio networks are mobile radio communication networks characterized by the existence of radio nodes (extension points) that provide retransmission capabilities. These radio nodes can be mobile terminals with special relay functionality (“ad hoc multi-hop networks”) or fix installed extension points, that operate exclusively as relays (“structured multi-hop networks”).

TABLE 2

Ad hoc multi-hop networks	Structured multi-hop networks
– No fixed installed additional infrastructure – Coverage depends on existence of further relaying mobile terminals in the area and cannot be reliably planned – May provide interconnectivity between mobile terminals in an area and also to access points – Mobile terminals must provide some kind of network functionality	– Extension points are installed as additional infrastructure – Coverage extension is guaranteed and is planned – Provides extended connectivity to the access point and relay capability for local communication

Multi-hop radio networks are able to use multiple subsequent wireless connections between a user terminal and a base station. Thereby other user terminals or fixed extension points enhance the coverage of a base station. The multiple subsequent wireless connections can be established within a homogenous system (e.g. cellular or RLAN system) or across different systems (e.g. some hops via cellular, some hops via RLAN systems).

3.2.6.2 Advantages of multi-hop radio network technology

Recommendation ITU-R M.1645 specifies as a target for systems “beyond IMT-2000” peak useful data rates of 100 Mbit/s (high mobility) and up to 1 Gbit/s (low mobility). Such data rates require large carrier bandwidths, which are most likely available only above 3 GHz. Both the large transmission bandwidths and the used frequency bands above 3 GHz will result in radio ranges that will be about one order lower than those of IMT-2000 systems.

This small range has a coverage and a capacity implication:

- In conventional single-hop radio networks small cell sizes would require correspondingly high numbers of base stations to achieve an ubiquitous coverage. This would increase the infrastructure costs.
- Small cell radii and the high data rates per cell lead to very high traffic capacities per area. This offered traffic capacity will very likely exceed significantly the average traffic demand per area. This leads to uneconomic network deployments.

Multi-hop radio network technology provide means to expand the coverage per base station and allow scalability of the radio network to match offered traffic capacity and demanded traffic capacity. Therefore this technology leverages fast deployment of wireless networks with low cost.

3.2.7 High altitude platform station (HAPS)

HAPS are stations located on an object at an altitude of 20 to 50 km and at a specified, nominal, fixed point relative to the Earth. In Regions 1 and 3, the bands 1 885-1 980 MHz, 2 010-2 025 MHz and 2 110-2 170 MHz and, in Region 2, the bands 1 885-1 980 MHz and 2 110-2 160 MHz may be used by HAPS as base stations to provide IMT-2000.

One proposed realization of a HAPS platform may consist of an extremely strong, lightweight, multilayer skin containing buoyant helium, a station keeping system consisting of GPS and an advanced propulsion system, a telecommunications payload, thin film amorphous silicon solar

panels for daytime power, and regenerative fuel cells for night time power. The enabling technologies are high efficiency solar cells and fuel cells that are both lightweight and durable, high strength ultra thin fibre and helium impermeable seal, thermal and pressure control/management techniques, as well as advanced phased antenna array and MMIC (microwave monolithic integrated circuit) technologies.

A HAPS is designed with a lifespan of five to ten years. Service beyond this term is limited by the gradual degradation of solar and fuel cells, structural fatigue and the decomposition of gas-storage modules. Ongoing advances in high strength, lightweight, UV-resistant composite materials, fuel cells, solar cells, and compact, high-speed semiconductor device will likely extend the lifespan of second generation HAPSs.

An IMT-2000 terrestrial system utilizing HAPS consists of communication equipment on one or more HAPSs located by means of station-keeping technology at nominally fixed points in the stratosphere (at about 20 km altitude), one or more ground switching/control stations, and a large number of fixed and mobile subscriber access terminals. The system uses radio transmission technologies (RTTs) that satisfy IMT-2000 requirements to offer high density and high-speed communications capacity to fixed and mobile stations. The HAPS architecture is in concept much like a very tall terrestrial tower that is sectorized into hundreds of cells.

The HAPS telecommunications payload consists of multibeam light-weight reflector or phased-array antennas, transmit/receive antennas for gateway links with ground switching stations, and a very large bank of processors that handle receiving, multiplexing, switching and transmitting functions. The payload can utilize various multiple-access techniques and standards (e.g., TDMA, CDMA) that meet IMT-2000 requirements. The HAPS telecommunications payload can be designed to serve as the sole station in a stand-alone infrastructure (essentially, replacing the tower base station network with a “base station network in the sky”) or can be integrated into a system that employs traditional terrestrial base station towers, satellites, and HAPSs.

A HAPS system will provide mobile cellular coverage and fixed wireless services to several regions ranging from a high-density (urban) area to low-density (rural) areas. The high gain transmit/receive antennas used on the HAPS project a large number of cells onto the ground in a pattern similar to that created by a traditional cellular system. The HAPS cellular coverage will likely include three regions:

- high-density (urban);
- moderate density (suburban);
- low-density.

The system dynamically reassigns capacity among the cells on a minute-by-minute basis in order to focus the capacity where it is most needed at any given time. For instance, the HAPS can direct additional capacity toward automobile traffic during rush hour and then shift it to a stadium during an evening sports event or performance. This gives the HAPS greater flexibility than traditional systems and can be used along or in concert with traditional terrestrial systems to prevent system overload in hotspots.

The above describes one system approach to HAPS. Alternate realization approaches are also feasible.

3.3 Mobile terminals

3.3.1 Terminal architecture

From the user's perspective, IMT-2000 and systems beyond IMT-2000 represent a fundamental change in expectation. Rather than merely expecting a "new and improved" but "static" collection of applications and services, the user will have an expectation of a dynamic, continuing stream of new applications, capabilities and services; a "Moore's Law" rate of advancement of new applications and capabilities.

Such a continuing stream will flow from a healthy ecosystem of general-purpose programmable platforms supported by a large, robust, and vibrant developer community.

New mobile user equipment (UE) are assuming characteristics of general-purpose programmable platforms by:

- containing high power general-purpose processors that follow Moore's law of dramatically increasing price/performance;
- providing a flexible, programmable platform that can be used for an ever-increasing variety of uses.

The convergence of wireless connectivity and a general-purpose programmable platform heightens some existing concerns and raises new ones, so that environmental factors as well as traditional technology and market drivers will influence the architecture of these devices.

Some important environmental factors are economic, security, and privacy.

Combining with the environmental factors we have traditional market and technology drivers: user value pull, security requirements pull, and technology enablers.

To maintain network and user space integrity, communications software will be "decoupled" and executed in parallel with user applications being written to a general-purpose processor running in a general-purpose execution environment. This partitioning maximizes the economic viability by allowing application development to evolve independent from communication standards, as well as enhancing security by providing autonomous network and user spaces.

Creating coexistent autonomy for the radio subsystem, application subsystem, and memory subsystems portions is evolving as a means to solve the triple environmental requirements of enabling economically viable products and services; while maintaining network and corporate security, and user sovereignty over application space and data privacy. Put anecdotally, "good fences make good neighbours".

3.3.2 RF micro-electro-mechanical systems (MEMS)

Future personal communication systems will require very lightweight, low power consumption, and small size. The requirements of IMT-2000 terminal such as small size, multifrequency bands, multi-mode and functional complexity demand the use of highly integrated RF front-ends and a compact system on chip solution. Despite many years of research, widely used discrete passive components based on electronic solutions cannot easily satisfy the above requirements of the future IMT-2000 terminal.

RF MEMS are integrated micro devices (or systems) combining electronic and mechanical components fabricated using an integrated circuit compatible batch-processing technique. This technology can yield small size, light weight, low power and high performance to replace discrete passive RF components such as VCO, IF, RF filters and duplexer. The system on chip using this technology can reduce the actual implementation size by 1/10.

As the users of the future wireless communication systems continually push handset manufacturers to add more functionalities, the manufacturers are confronted with trade-offs among cost, size, power and packaging constraints. It is anticipated that RF MEMS will emerge as a breakthrough technology to satisfy these constraints of future terminals. The commercialization of RF MEMS for future terminals will be within the next five years.

3.3.3 New innovative user interfaces

How the user experiences new telecommunications technology, depends on the services offered but also on the usability, design and quality of the terminals. Wearable computing is a popular study item at universities worldwide, giving new ideas of man-machine interfaces applicable also for mobile terminals.

Text messaging is the killer data application of today and a very frequency efficient way of communicating compared e.g. to a voice call. Multimedia messaging is expected to be the next boom, requiring a large display. Combining a practical text input method and a large enough screen on a single small terminal is a challenge.

So far, many of the solutions offered, e.g. for text entry, are not open standards but proprietary methods including IPRs. Proposed physical keyboards often tend to add features and/or buttons to the conventional dialling keypad instead of decreasing the number of keys that could instead be the goal in order to minimize the space required.

There is also a clear need for harmonization and for recommended use of common open interface standards in this area. For example, if a user gets used to one type of keyboard and becomes a committed and skilled user of it, she or he will get frustrated if the next phone, new version or another brand, has a different or slightly different user interface solution and the learning curve must be restarted.

3.3.3.1 One example of a new physical interface

Annex 13, as an example, describes a proposed method for combining text entry and a large display on a single compact mobile terminal. The presentation of the global keyboard optimized for small wireless devices (GKOS) back panel keyboard demonstrates that completely new types of physical user interfaces can still be found, and hopefully encourages manufacturers to study this issue more and maybe further refine the proposed concept to obtain a common standard for this kind of solution. The concept is an open standard and was first published on 5 October 2000. For more detailed information on GKOS, check also <http://gkos.com/>.

3.3.4 Reconfigurable processors, terminals and networks

3.3.4.1 Summary of the technology

Since bit-level data processing is needed in such areas as interleaving, error correction and detection, ciphering, and scrambling in mobile communication systems, particularly in baseband digital processing of mobile terminals as well as base stations, a processor which can perform high-speed bit-level data processing is required. However, general purpose processors, such as CPUs or DSPs, are not suitable for bit-level operation, and hence, a well-designed embedded processor with a reconfigurable unit is required so that user defined instructions are efficiently executed. It has a special execution unit for user custom instructions, other than normal execution units such as an integer execution unit. The special execution unit can be designed to be suitable for bit-level data processing, and it is realized with reconfigurable circuitry because custom instructions are different from application to application.

As shown in Annex 14, a typical reconfigurable processor has configuration information which defines connections between circuit elements in the execution unit and functions of those circuit elements, where the configuration information is supplied from configuration memory. It also has the capability that various custom instructions are executed by changing a corresponding address of the configuration memory. The configuration information can be updated in one clock cycle while the configuration memory can hold a set of configuration information. They can be rewritten in run-time, which allows users to define instructions other than the predefined ones. In a typical prototype, as shown in Annex 14, the configuration information is 256-bit length, the configuration memory can hold 32 sets of configuration information, and the size of reconfigurable circuit is about 50 K gates including a configuration memory, occupying several per cent of the entire size of the processor. This technology is also applicable to base stations.

3.3.4.2 Advantages of the technology

Since this type of processor has a reconfigurable unit that can handle many kinds of bit-level data processing, it can be applicable to various applications for mobile communication systems with efficient operation. For instance, the performance of the processor with the reconfigurable unit for processing a data encryption standard (DES) algorithm is more than six times higher than that of a processor without a reconfigurable unit. The processor can also be applicable to wireless communication systems, for instance, to Bluetooth digital baseband processing such as forward error correction (FEC), cyclic redundancy check (CRC), or scrambling at a speed a few times faster than conventional processors.

3.3.4.3 Issues to be considered

The reconfigurable unit is designed aiming for bit-level data processing and is suitable for various bit-level data processing tasks. It is applicable to some processing necessary for wireless communication systems. On the other hand, consideration needs to be given to another type of digital baseband processing which handles byte-level or word-level (non-bit level) data. For those types of data processing, especially for enhanced IMT-2000 or systems beyond IMT-2000, it might be necessary to either extend the reconfigurable unit or to adopt a different type of reconfigurable

unit. This approach may result in the inevitable implementation of silicon devices of a huge scale, and hence, careful consideration needs to be given in terms of comprehensive efficiency, gate size, power consumption, and applicability.

4 Conclusions

This Report provides useful information on some of the technology enablers which are foreseen, such as the spread of IP-based technologies, increasing signal processing power in semiconductors and the enlargement of transport capacity in networks. Those technology enablers are in different areas, such as new radio technologies having an impact on spectrum utilization, access network and radio interfaces, mobile terminals, and system-related technologies.

It is expected that those technologies will be considered in the research and development of, but not necessarily used for, the future development of IMT-2000 and systems beyond IMT-2000. While this Report does not give an exhaustive list of potential technologies for the future development of IMT-2000 and systems beyond IMT-2000, it should be noted that other newly emerging technologies that are not covered in this Report would be taken into consideration as well.

5 Terminology, abbreviations

Table 3 provides an explanation of the terminology used for the current and enhanced IMT-2000 terrestrial technologies, and may prove useful in understanding the background to some of the topics presented in this Report.

TABLE 3

IMT-2000 terrestrial radio interfaces

Full name	Common names
IMT-2000 CDMA Direct Spread	UTRA FDD WCDMA UMTS
IMT-2000 CDMA Multi-Carrier	CDMA2000 1X and 3X CDMA2000 1xEV-DO CDMA2000 1xEV-DV
IMT-2000 CDMA TDD (Time-Code)	UTRA TDD 3.84 Mchip/s high chip rate UTRA TDD 1.28 Mchip/s low chip rate (TD-SCDMA) UMTS
IMT-2000 TDMA Single-Carrier	UWC-136 EDGE
IMT-2000 FDMA/TDMA (Frequency-Time)	DECT

The following listing of abbreviations and their meaning may similarly prove useful.

AA	Adaptive antennas
AAA	Authentication, authorization, accounting
ALU	Arithmetic-and-logic unit
AMC	Adaptive modulation and coding
API	Application programming interface
ARPU	Average revenue per user
BAC	Basic access component
BAN	Basic access network
BASM	Basic access signalling manager
BMM	Bandwidth management module
BS	Base station
BSI	Base station interface
CCN	Common core network
C/I	Carrier-to-interference ratio
CMM	Configuration management module
C/N	Carrier-to-noise ratio
CoMM	Cooperative mode monitoring
CRC	Cyclic redundancy check
CSI	Channel status information
CU	Central unit
DES	Data encryption standard
FDD	Frequency division duplex
FEC	Forward error correction
GKOS	Global keyboard optimized for small wireless devices
HAPS	High altitude platform station
H-ARQ	Hybrid ARQ
HDRPN	High data rate packet nodes
HRM	Home reconfiguration manager
IP	Internet Protocol
IMSI	International mobile subscriber identity
LMM	Local mobility management
LOC	Locator component
LRM	Local resource manager



MCS	Modulation and coding scheme
MEMS	Micro-electro-mechanical systems
MIMM	Mode identification & monitoring module
MIMO	Multiple-input multiple-output
MNSM	Mode negotiation and switching module
MUT	Multiservice user terminal
NI	Network interface
PAN	Personal area network
PDA	Personal digital assistant
PRM	Proxy reconfiguration manager
RAN	Radio access network
RAT	Radio access technology
RAU	Remote antenna units
RHAL	Radio hardware abstraction layer
RoF	Radio on fibre
RRM	Radio resource management
RSSI	Received signal strength indication
SDP	Session description protocol
SDR	Software defined radio
SDRC	Software download and reconfiguration controller
SDR-CF	SDR core framework layer
SHO	Soft hand-off
SIP	Session initiation protocol
S/N	Signal-to-noise ratio
SPRE	Software download and profile repository
SRM	Serving reconfiguration manager
SWD	Switched diversity
TDD	Time division duplex
TRSA	Terminal reconfiguration serving area
UE	User equipment
UWB	Ultra-wideband
WAP	Wireless application protocol

Annex 1

Technologies for improving bandwidth efficiency

1 Bunched systems

1.1 Introduction

In pedestrian and indoor environments, there will be severe fluctuations in traffic demands, high user mobility and different traffic types. This highly complex environment will require advanced RRM algorithms. It will be beneficial to have a central intelligent unit that can maximize the resource utilization.

The bunched system consists of a limited number of RAUs that are connected to a functional entity named central unit (CU). All intelligence as well as significant parts of the signal processing are located in the CU. The RAUs are simple antenna units capable of transmitting and receiving user signals. The local centralization at the CU level permits the use of near optimal algorithms for resource management because the CU has complete knowledge of all allocated resources at any time. This results in very efficient resource utilization within the bunched system. Furthermore, the bunched system can be enhanced to allow the RAN to detect changes, make intelligent decisions, and implement appropriate actions, either minimizing or maximizing the effect of the changes.

With a major shift from voice to high-data rate services for systems beyond IMT-2000, it is necessary to increase the system capacity. Bunched systems are well suited for hotspot applications. The coverage of bunched systems can be extended easily and has any desired geometrical shape. The move towards smaller cells will also make RAN planning process intrinsically more difficult and expensive. The bunched system can coexist with pre-existing microcell and cooperates with other bunched systems when it organizes the wireless network. Design issues of the RAN architecture and the RRM algorithms for the bunched systems must be addressed.

1.2 System characteristics

System characteristics and benefits of bunched systems are described and compared with those of conventional system.

– *Locally-centralized architecture*

Bunched systems consist of a CU and multiple RAUs, and these RAUs are connected to the CU. Because all transceivers are installed in the CU, all the channel resources are controlled by the CU. Therefore, bunched systems have a locally centralized architecture where a CU controls all the RAUs. This system is different from the conventional cellular system by having one or multiple antennas at a cell site.

– *Hierarchical cell structures of RAN*

Bunched systems can be regarded as the lowest cell layer, which covers dense traffic areas in a hierarchical cell structure. This system can coexist with existing macrocells as well as other bunched systems. Bunched systems are suitable for high speed data services in urban and indoor areas.

– *Dynamic load distribution*

Bunched systems can disperse system load concentrated on small regions. When traffic load is concentrated on one of the RAUs, the CU maintains service QoS by allocating more channel resources on that RAU.

– *Dynamic RRM*

Bunched systems can manage channel resources dynamically, since the CU can synchronize all the RAUs. By having transceivers in the CU, the CU can control all the channel resources. Borrowing of channel resources between RAUs can be controlled easily, making RRM dynamic and adaptive in an environment where large traffic change occurs.

– *Adaptive coverage control*

In bunched systems, coverage can be extended easily and the network can be planned as expected. This is achieved by deploying additional RAUs where coverage extension is needed. Moreover, dead spot problems can be solved by installing RAUs flexibly according to the radio network circumstances.

1.3 Required system control algorithm

Required algorithms are presented for bunched systems operation and construction. There are two types of algorithms, one is for control within a bunch (i.e. intra-bunch) and the other is for control between adjacent bunches (i.e. inter-bunch).

– *Intra-bunch*

– Dynamic multicasting

A dynamic multicasting scheme is used to improve the system performance. An RAU selecting scheme can be applied as a dynamic multicasting technique. With the selecting scheme, the interference is reduced by transmitting the signal through selected RAUs. Thus, an optimized selecting algorithm is needed.

– Adaptive RAU coverage control

Coverage control can disperse heavy traffic load from an RAU to another. This prevents QoS degradation and high-speed data service can be provided easily. Traffic load in each RAU must be measured, and an algorithm for adjusting RAU coverage according to load variation is needed.

– Handover between RAUs within a bunch

When a user moves into an adjacent RAU in the system with dynamic multicasting, handover between RAUs is needed. However, handover is not required in a system without dynamic multicasting, i.e. when a user signal is broadcast within a bunch. Serving RAU must be switched to another if only one RAU is selected for transmitting at any time. If the signal is transmitted through multiple RAUs, a group of the selected RAUs must be updated.

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- Macro diversity techniques

Various multipaths of radio propagation are generated between multiple RAUs and a mobile terminal. Path diversity can be utilized, because signals are received through different paths of different RAUs. In this case, an algorithm is required to combine the received signals to get a macro diversity gain.

- Radio on fibre (RoF) technologies for RAU and CU links

RoF technologies are required to transfer signals between RAUs and the CU. RoF technologies can be used for a transmission scheme in which the radio signals are modulated to the optical signal. All the RAUs and the CU will require devices and algorithms for successful conversion of optically modulated signals into radio-modulated signals.

- *Inter-bunch*

- Dynamic resource assignment

Dynamic resource assignment can utilize radio resources effectively. Dynamic resource assignment schemes such as dynamic frequency allocation and power control can reduce interference between bunches, and improve system performance. Network status must be measured continuously to dynamically manage resources.

- Adaptive bunch coverage control

Coverage control can disperse heavy traffic load between bunches. Load dispersion by coverage control allows high speed data service. Therefore, like RAU coverage control, a coverage control algorithm according to load variation is required as well.

- Handover between bunches, and between bunches and macro BSs

Handover between bunches is needed when a user passes through bunches controlled by different CUs. When a user moves from a bunch service area to a macro BS area, a handover between different system layers is also required.

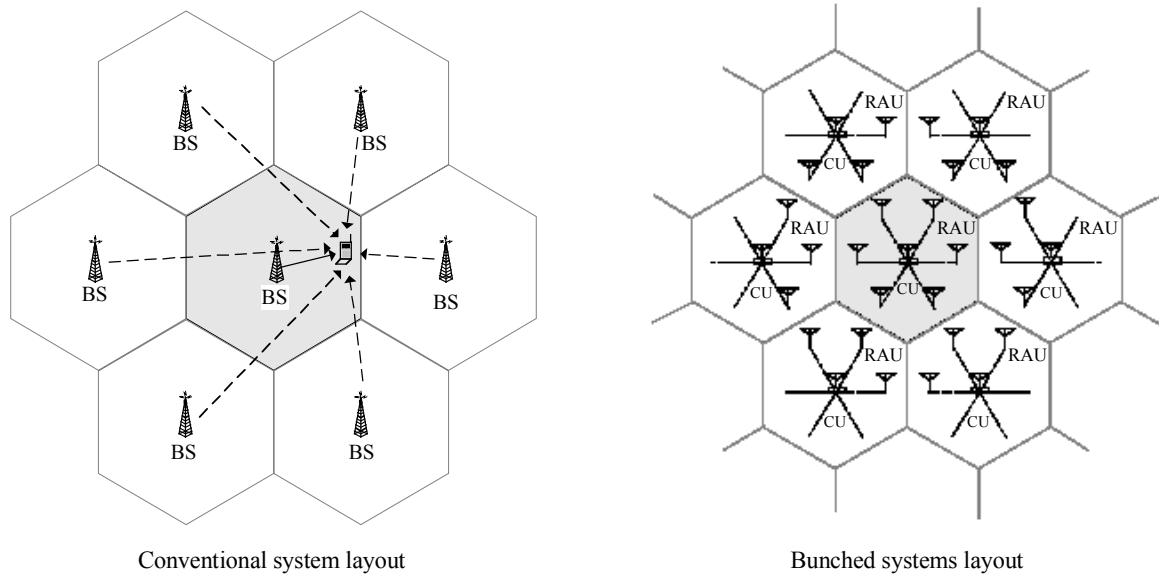
1.4 Illustrative capacity analysis of bunched systems

The bunched systems' capacity is evaluated in this section by applying the technology to CDMA radio access networks. Most studies on bunched systems have been focused on improving trunking efficiency in bandwidth limited systems (e.g. FDMA or TDMA systems) [Ariyavisitakul *et al.*, 1996]. Another benefit of bunched systems is reduction of path loss between terminal and RAUs, leading to the capacity improvement in interference-limited systems such as CDMA networks. When applying bunched systems to CDMA radio access networks, interference power on uplink can be decreased, increasing the capacity [Spilling *et al.*, 1999]. The next generation system requires efficient utilization of radio resource on downlink more than on the uplink, due to the traffic asymmetry. In this section, the downlink capacity gain of bunched systems over the conventional cellular system is derived and presented.

1.4.1 Model

Conventional BS systems and bunched systems in CDMA RANs are considered. Bunched systems consist of a CU and multiple RAUs. A cell consists of one BS in the conventional system, but multiple RAUs with one CU in the bunched systems. Both systems are modelled by locating BSs and CUs, respectively, at the centres of a hexagonal grid pattern as shown in Fig. 4.

FIGURE 4
System layout



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Performance measure includes outage probability and BS transmission power. In a conventional system, received E_b/N_0 on downlink can be represented as follows:

$$\left(\frac{E_b}{N_0} \right)_{i,j} = \frac{P_{i,j} / L(d_{i,j})}{I_{sc} + I_{oc} + N_0 W} \cdot \frac{W}{R_i} \quad (1)$$

where:

i : index of terminal

j : index of BS

$P_{i,j}$: power allocated to i -th terminal at j -th BS

W : spreading bandwidth

R_i : data rate

$N_0 W$: thermal noise power

$L(d_{i,j})$: path loss between j -th BS and i -th terminal (including antenna gain).

In bunched systems, the received E_b/N_0 can also be represented as follows:

$$\left(\frac{E_b}{N_0}\right)_{i,j} = \sum_{k=0}^{\text{Number of RAUs}} \left(\frac{P_{i,(k,j)} / L(d_{i,(k,j)})}{I_{sc,sr} + I_{sc,or} + I_{oc} + N_o W} \cdot \frac{W}{R_i} \right) \quad (2)$$

where:

i : index of terminal

k : index of RAU

j : index of CU

$P_{i,(k,j)}$: power allocated to i -th terminal at k -th RAU of j -th CU

$P_{(k,j)}$: total transmission power of k -th RAU of j -th CU

$L(d_{i,(k,j)})$: path loss between i -th terminal and k -th RAU of j -th CU (including antenna gain)

$I_{sc,sr} = (1 - \rho_{sr})(P_{(k,j)} - P_{i,(k,j)}) / L(d_{i,(k,j)})$: interference level from same RAU within a bunch

$I_{sc,or} = (1 - \rho_{or}) \sum_{t \neq k}^{\text{Number of RAU}} P_{(t,j)} / L(d_{i,(t,j)})$: interference level from different RAUs within a bunch.

In bunched systems, the maximal ratio combining scheme utilizing macro diversity between RAUs can be applied to improve the received E_b/N_0 . An ideal maximal ratio combining scheme is assumed in the above equation.

In the conventional cellular system, the received interference can be divided into same cell and other cell interference as shown in equation (1). In bunched systems, same cell interference can be regarded as the sum of two different interferences. One is a received interference level from the same RAU within a bunch, i.e. $I_{sc,sr}$, the other is an interference level from different RAUs within a bunch i.e. $I_{sc,or}$. The received signals from different RAUs along other paths can be less orthogonal to the desired signals than those from the same RAU. This reduction of orthogonality is considered in equation (2).

Outage is defined as an event where the BS (or RAU in bunched systems) has insufficient power to maintain the received E_b/N_0 at the required E_b/N_0 . Hence, outage probability can be defined as follows:

$$P_{outage} = P \left(\left(\frac{E_b}{N_0} \right)_i < \left(\frac{E_b}{N_0} \right)_{req} \mid P_{TX} \geq \text{Maximum BS or RAU transmission power} \right) \quad (3)$$

1.4.2 Results

A computer simulation is developed for the performance evaluation. A WCDMA FDD system is selected as the system model. System parameters and the default values set for the analysis are listed in Table 4.

The bunched systems have one CU and seven RAUs. Each RAU is located at the $2/3$ radius from the centre. The Monte Carlo simulation model consists of two tiers, and data from the centre cell is collected for statistics. The maximum transmission power of the BS is 20 W both in the bunched

systems and the conventional system. Then each RAU in the bunched systems is considered to have a transmission power limitation of $20/7$ W.

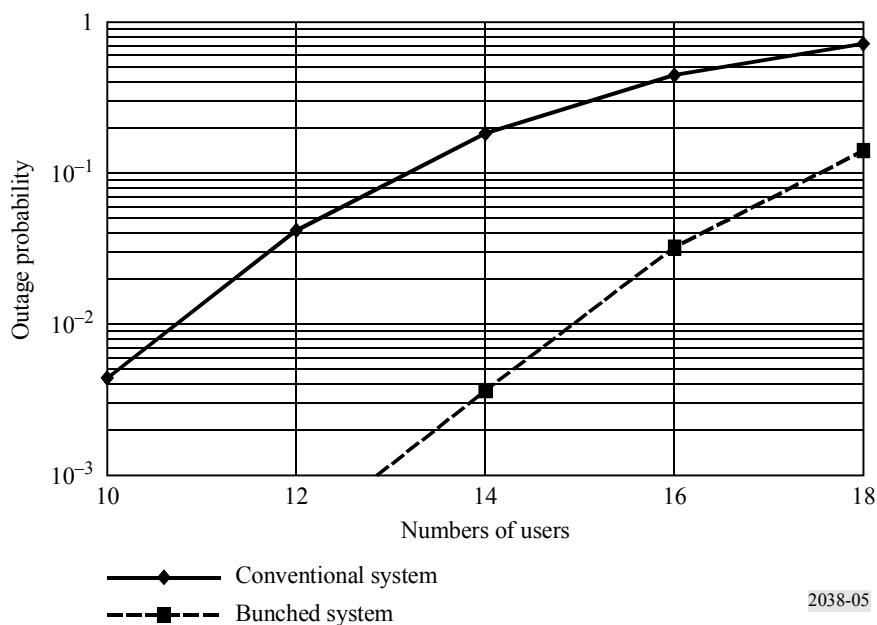
TABLE 4
Applied system parameters

Parameter	Value
Cell radius	1 km
Chip rate	3.84 Mchip/s
Shadowing STD	8 dB
Overhead Channel power ratio	0.15
Antenna gain	15 dBi
Data rate	64 kbit/s
Required E_b/N_0 in downlink	5.4 dB
User distribution	Uniform distribution
Orthogonality within a RAU	0.6
Orthogonality between different RAUs	0.3
Cell TX power	20 W (43 dBm)
Power control	Perfect

1.4.2.1 Outage probability

Outage probabilities with various number of users are shown in Fig. 5. The results show that CDMA bunched systems can accommodate more users than the conventional system. It can be seen that the downlink capacity can be increased about 40% with the QoS goal of 1% outage.

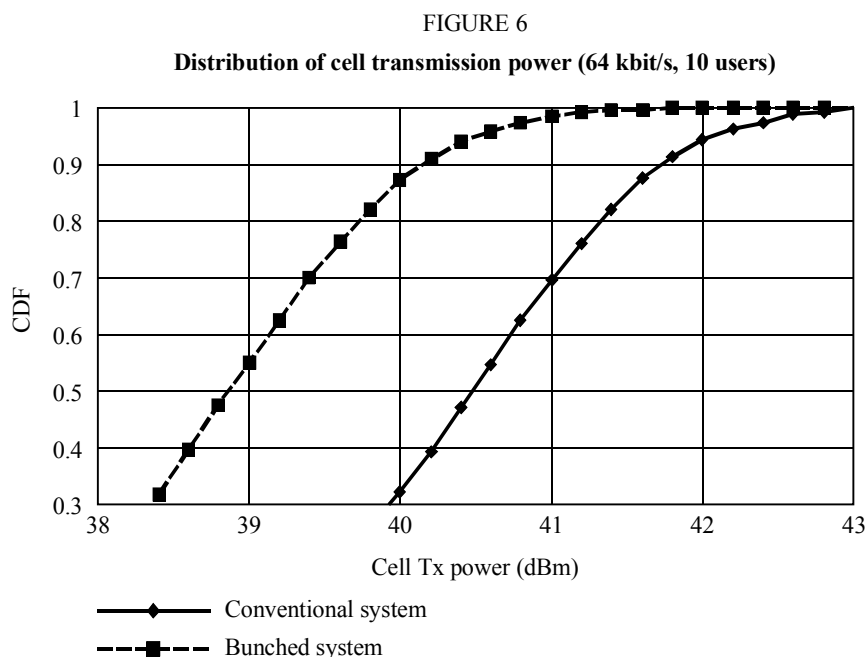
FIGURE 5
Outage versus number of users (64 kbit/s)



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1.4.2.2 Total BS (or CU) transmission power

Figure 6 shows the cumulative distribution functions (CDF) of the BS and CU transmission powers. The result shows that CDMA bunched systems transmit lower power than the conventional system. The improvement is about 2 dB at median value. In the bunched systems, signal attenuation between user and RAUs is smaller than that of conventional cellular system, because distributed antennas are closer to the user. As the required transmission power is reduced, interference power decreases and more users can be accommodated.



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2 Ultra-wideband technology

There are further possible access techniques under development like UWB technology. To date no internationally agreed definition of UWB exists because the applications and uses of these devices may be put to, for communications and other uses, are very diverse and have not been fully developed. Because many UWB devices and applications may be developed that have different technical and operational characteristics, the regulatory and interference impacts of UWB devices are not known yet. One administration has, however, adopted rules including technical standards and spectrum restrictions for low power UWB operations in an attempt to ensure that existing and planned radio services are adequately protected³. The applicability of UWB technology depends on the setting of appropriate interference limits and limitations on spectrum allowed for operation. The basic concept of UWB is to develop, transmit and receive an extremely short duration burst of RF energy. The resultant waveforms are extremely broadband (typically some gigahertz).

³ The United States Federal Communications Commission adopted a First Report and Order, on 14 February 2002, on UWB transmission systems. See In the Matter of Revision of Part 15 of the Commission's Rules, Regarding Ultra-Wideband Transmission Systems, ET Docket 98-153, First Report and Order, 67 FR 34872, May 16, 2002. The document is available on the Internet at: http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-02-48A1.pdf.

A time modulated ultra-wideband (TM-UWB) transmitter emits specially formed ultra-short pulses (or, monocycles) with tightly controlled pulse-to-pulse intervals. This can result in low average power, noise-like, CW-like, or pulse-like signals that can transmit data, voice and video communications or can be used as a personal radar, or as a positioning and tracking device. Single RF monocycles can be transmitted through a broadband antenna, and, by using a matched receiver, can be recovered again.

Known TM-UWB systems usually use pulse position modulation on a pulse-by-pulse basis. The receivers use a cross-correlator that gives the receiver the ability to detect and recover the signal. A single bit of information is generally spread over multiple monocycles. The receiver coherently sums the proper number of pulses to recover the transmitted information. This greatly increases the processing gain.

The extremely short pulse duration allows for a large number of transmit time slots. By shifting each monocycle's actual transmission time over a large time-frame in accordance with a suitable code, one can channelize pulse trains. In a multiple access system, each user would have its own code sequence. Only a correlation receiver operating with the same template waveform (e.g., code sequence) can decode the transmitted signal.

Presently, the effects of interference to digital communications systems from narrow pulses have not been widely studied, nor is there operational experience. In particular, CDMA cellular systems rely for their operation on fast power control. This is usually signalled over the radio interface using a few data bits (which are not interleaved because of the need for a fast response time). This means that digital communications systems (and cellular systems in particular) may be susceptible to interference that consistently corrupts particular bits within the transmitted data. For this reason, careful attention has to be spent on the compatibility of UWB systems with CDMA cellular systems, until the characteristics of the UWB emissions and their effect on digital communications are better understood.

More generally, some administrations have begun examining UWB technology and are engaged in extensive analyses of technical and national regulatory aspects of implementing UWB devices, including the potential for harmful interference from UWB devices into other systems, particularly safety-of-life services.

3 AMC (adaptive modulation and coding) and hybrid ARQ (H-ARQ)

IMT-2000 and systems beyond IMT-2000 are considering supporting a wide range of services, including high rate multimedia services. Such a growing demand for capacity makes it important to maximize the spectral efficiency. Various techniques have been proposed to make wireless communications systems spectrally efficient. One of the important research areas regarding this issue is AMC (adaptive modulation and coding). AMC can be used to increase transmission rates over fading channels. AMC schemes adapt to channel variation by varying parameters such as modulation order and code rate. The basic principle of AMC is to change the MCS based on the channel status information (CSI). Therefore, the scheduler has to know about CSI in order to select

the appropriate modulation and coding scheme. Errors in the channel estimation, however, may cause the scheduler to select the wrong MCS level. Delay in reporting channel information also reduces the reliability of the estimated CSI due to the continuously varying mobile channel.

H-ARQ (hybrid ARQ) can be combined with AMC to increase overall performance. It enables the implementation of AMC by reducing the number of required MCS levels and the sensitivity to measurement error and feedback delay. Two well-known methods for H-ARQ are chase combining and incremental redundancy (IR). The chase combining method involves the retransmission by the transmitter of the coded data packet. The decoder at the receiver combines these multiple copies of the transmitted packet according to the received S/N . Thus, diversity gain is obtained. IR is another way for the H-ARQ technique wherein, instead of sending simple repeats of the entire coded packet, additional redundant information is incrementally transmitted if the decoding fails on the first attempt.

3.1 Adaptive downlink modulation based on user location, received C/I level, and required transmission rate

3.1.1 Introduction

Many modulation schemes such as single carrier (SC), direct spread (DS)-CDMA, orthogonal frequency division multiplexing (OFDM), multicarrier (MC)-CDMA have been proposed for mobile systems, nomadic wireless access and fixed wireless access. The selection of radio interface depends on the specifications of the system. OFDM is an attractive modulation scheme for its high immunity to multipath fading and its capability of offering high transmission rate. However, the link quality of the OFDM system is degraded when the co-channel interference signal level from adjacent cells is increased. On the other hand, the spread spectrum technique has tolerance to co-channel interference but it is difficult to enhance its transmission rate per user by restriction of allocated bandwidth.

OFDM and CDMA combined modulation schemes such as MC-CDMA and MC-DS/CDMA are attractive techniques that increase the processing gains in the frequency domain and time domain, respectively. In addition, the OFDM and CDMA combined scheme offers high transmission rate under multipath fading environments and mitigates co-channel interference from adjacent cells. However, bit error rate performance deteriorates when orthogonality between sub-carriers and spreading codes are degraded by large delay spread, frequency offset and other factors.

3.1.2 Technology concept

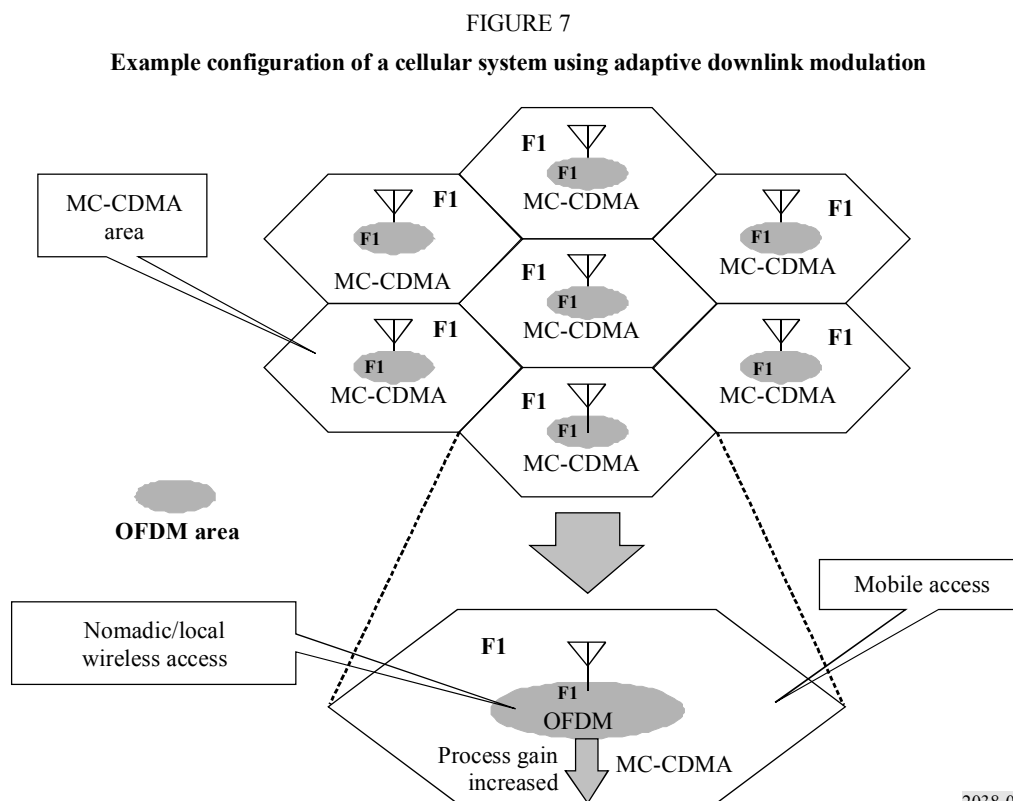
As explained above, each modulation scheme has distinct physical features. Namely, schemes have advantages and disadvantages in accordance with channel conditions such as C/N , C/I , delay spread, and other parameters.

Adaptive downlink modulation based on user location, received C/I level, and required transmission rate will be a candidate for enhancing the system capacity that allocates the preferable modulation scheme to each time slot per user. The features of the adaptive downlink modulation are summarized as follows.

- The base station (BS) allocates the preferable modulation scheme to each user per each time slot in accordance with link conditions such as propagation distance, received signal strength indication (RSSI) level, interference signal strength, delay spread, and required transmission rate of each user.
- Each time slot should be occupied by a single modulation scheme to avoid interference between different radio interfaces. Timing synchronization between multiple cells will be accomplished using GPS without any difficulty.
- The transmission power of each time slot is set to a different value in association with the modulation scheme. Transmission power control technique can also be applied to each modulation scheme with a different control algorithm.
- The channel frequency can be reused in every radio cell by allocating a different modulation scheme according to user location.

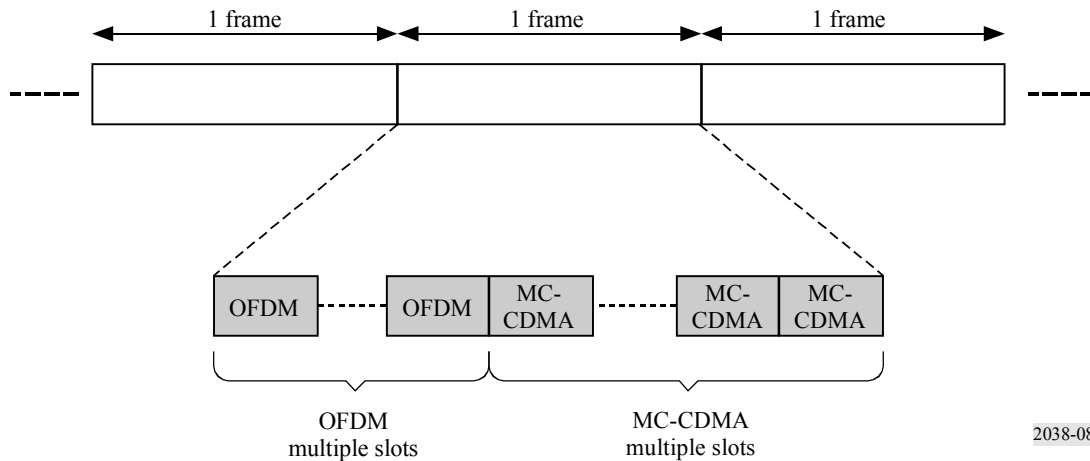
3.1.3 Example configuration

Figure 7 presents an example configuration of a cellular system adopting the adaptive downlink modulation scheme. OFDM and MC-CDMA are selected as the example modulation schemes for the adaptive downlink modulation scheme. The frame structure of the cellular system is arranged as shown in Fig. 8. In this Figure, a frame is divided into multiple slots. Some slots are allocated for OFDM and others are for MC-CDMA. Time synchronization of the frame and slot will be established between adjacent BS by GPS or other methods. Interference between OFDM and MC-CDMA can be avoided by allocating the time slots for each system independently.



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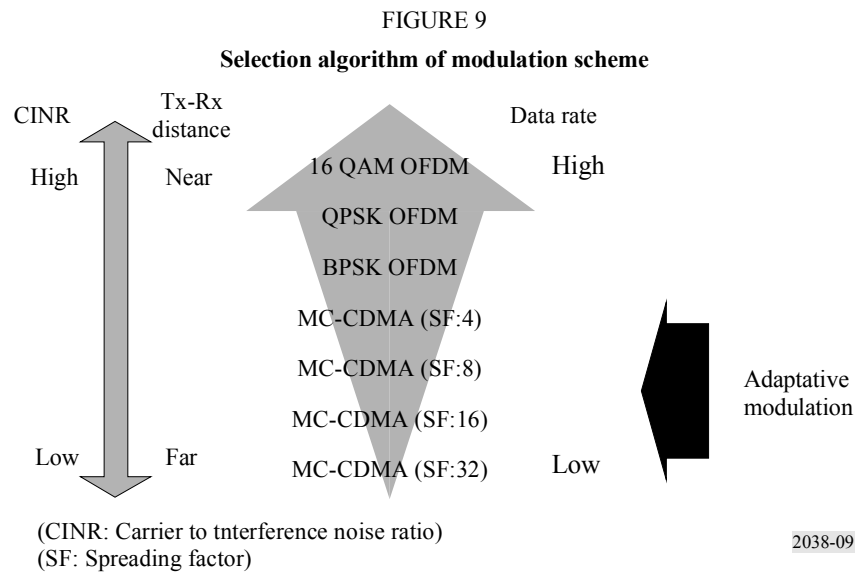
FIGURE 8
Example frame structure



The transmission power for OFDM slots are set lower than that of MC-CDMA slots to avoid the co-channel interference between adjacent cells. In this case, service areas of OFDM slots are restricted around the BS and do not overlap as shown in Fig. 7. Therefore, the same channel frequency can be allocated in every cell, which will enhance the efficiency of channel utilization. This service area will be adequate for nomadic/local wireless access services with high data rate.

On the other hand, the transmission power of MC-CDMA slots is set higher than that of OFDM slots. The service areas of MC-CDMA are extended and overlapped as shown in Fig. 7. Co-channel interference between adjacent cells is mitigated using spreading code in the frequency domain. The selection of spreading code per user should take into account the orthogonality between the other codes used in the same cell and adjacent cells. As the same service areas of MC-CDMA signals are deployed as the current cellular systems, users will be able to establish their communication link under high mobility environments.

Figure 9 presents an example selection algorithm for the modulation scheme. When the CINR of the channel is high, the distance of the wireless link is short and the required transmission rate of the user is high, the BS assigns an OFDM slot with high rate modulation such as 16-QAM with high coding rate. If the CINR is very low and the distance of the wireless link is long, the BS allocates an MC-CDMA slot with high spreading factor and low coding rate to maintain the communication link. The concept of this algorithm is based on the combination of adaptively allocating the radio interface and adaptive selection of its parameters. As a consequence, the adaptive downlink modulation scheme will enhance the system capacity of wireless communications systems by allocating a preferable modulation scheme to each time slot per user.



3.1.4 Conclusion

The adaptive downlink modulation scheme will be a promising technology for enhancing the system capacity of wireless communications systems by allocating the preferable modulation scheme to each time slot per user. Using this technique, the same channel frequency will be reused in every radio cell by allocating a different modulation scheme according to user location. Furthermore, co-channel interference from different modulation schemes will be avoided by separating the slot timing for each modulation scheme on time-basis. Transmission power of each radio interface is changeable to form different beam coverage. This feature will offer different service quality to different users in accordance with their requirements and channel conditions. By allocating the modulation scheme and its parameters (mapping pattern, coding rate, spreading factor, etc.) adaptively, users will be able to maintain their communications even in severe wireless environments.

The adaptive selection algorithm for the modulation scheme requires further consideration in conjunction with the specifications required for systems beyond IMT-2000. The number of slots per frame, slot length, frame length, and frame format for the system require examination. In addition, modulation type, coding rate, transmission power and other parameters for radio interface require appropriate selection for the adaptive downlink modulation technology to achieve high bandwidth efficiency. The measurement method for C/I , C/N , distance between the BS and MS, and delay spread have to be considered. The technologies combined with adaptive array antenna, diversity, space time coding, MIMO require further study to optimize the improvements.

4 Flexible spectrum sharing

4.1 A method for flexible inter-operator spectrum sharing

The radio-frequency spectrum resource is scarce and expensive. Spectrum efficiency of the cellular systems must, therefore, be optimized. This is critical especially in the presence of several competing operators in the same frequency band. Spectrum resources available to each operator should be dynamically adjusted to its needs. Sharing of frequency carriers between different operators is a method to optimize the use of these resources.

The spectrum allocation process is nowadays not very flexible. Indeed, operators are allocated a fixed amount of spectrum and they are committed to *a priori* some objectives in terms of amount of traffic and coverage. If they do not meet these commitments, part of their spectrum can be reallocated to other operators in need. However, this method may take a long time and is not flexible enough. Besides, it is not suitable if the under-utilization of spectrum occurs in peaks. A dynamic way of reallocating spectrum according to traffic needs is necessary.

This Report proposes a method to enable sharing of frequency carriers between different operators by dynamically adjusting a set of thresholds without any need of load information exchange between the operators, thereby prioritizing spectrum efficiency.

4.1.1 Description

4.1.1.1 Preamble

Frequency carriers can be shared between several operators to improve spectrum utilization. For example, in the following, frequency spectrum is used by two operators A and B, F_A and F_B are “proprietary frequencies”, only network A and B respectively can use them. F_{shared} are two frequency carriers shared among networks A and B. That implies that mobile users of both networks may be assigned to these shared frequencies, depending on the load conditions. In this case, each network can potentially use up to four frequency carriers. Radio resource can therefore be adapted to the traffic needs, resulting in improved spectrum utilization.

FIGURE 10
Spectrum allocation with frequency sharing

F_A	F_A	F_{shared}	F_{shared}	F_B	F_B
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The objective of this technology trend is to propose a method for the management of these shared frequency carriers, bearing in mind the four principles mentioned above, by defining:

- admission rules of mobile users, either by direct access or hand-over;
- load control;
- priority management between operators for the use of shared carriers.

4.1.1.2 Terminology

Four thresholds are used in order to manage the load or the number of users on the frequency carriers:

- $T_{\text{admission}}$: new call admission threshold;
- $T_{\text{HO accept}}$: hand-over requests admission threshold;
- $T_{\text{HO depart}}$: hand-over departure threshold;
- T_{drop} : drop threshold, to start disconnecting some mobile users to ensure that certain quality of service is maintained (drop calls anyway since outage conditions).

Difference between T_{drop} and $T_{\text{HO_depart}}$ should be defined by outage risks to warrant the best trade-off between outage probability and overall resources utilization.

4.1.1.3 Description of the proposed method

In case of the shared frequencies, two sets of these four thresholds are defined:

- *Default threshold set* refers to values of thresholds that are used to prevent the use of the shared frequency carriers.
- *Target threshold set* refers to values of thresholds when shared frequency carriers are used.

Each operator has the freedom to vary the four thresholds used on the shared frequency, *provided that they remain within the default and the target threshold sets*. The target and default threshold sets can be pre-defined or changed dynamically during the operations.

Basically, each operator uses a target set of thresholds that is different from the other operators. Priority rules are generated automatically by the relative difference of target thresholds between the operators. For example, if operator A uses a T_{drop} of 14 dB while operator B uses a T_{drop} of 20 dB, operator A begins to drop its mobile users before operator B starts to do so. *Dynamic setting of the priority rules is enabled in this way*. Moreover, the cost of using these frequency carriers can be easily derived by comparing the respective threshold values used.

4.1.1.3.1 Load control on the shared and proprietary frequency

In the following, we will illustrate the method using noise rise thresholds. However it should be noted that other measurement criteria are available, such as total power transmitted by BS, system outage, etc.

There is a set of thresholds for each operator on the shared frequencies, that are dynamically adjusted, depending on the loading conditions, as explained in the two cases below.

4.1.1.3.1.1 Proprietary frequency carriers are not fully loaded

The mobile users on the shared frequency carriers are to be handed-over to the proprietary frequencies. Admission of mobile users on the shared frequency carriers is stopped and the hand-over of the users from the shared to the proprietary carriers has to be favoured.

In this case, $T_{\text{admission}}$ and $T_{\text{HO_accept}}$ decreases, and $T_{\text{HO_depart}}$ as well to make the users leave the shared frequency. The T_{drop} can remain at the same level in order to control the outage on the shared frequency.

The adjustment of the thresholds should not be blind in order not:

- to overload the proprietary frequency carriers;
- to overload the system by performing too many inter-frequency handovers.

The final result is that all users will leave the shared frequency, either by hand-over and if not, at the end of their call.