10 September 2002

Mr. Fabio Leite
IMT-2000 Project Manager
International Telecommunication Union
Place des Nations
CH-1211 Geneva 20
Switzerland

Dear Mr. Leite,

The Software Defined Radio Forum has corresponded in the past with the International Telecommunication Union (Radiocommunication Bureau) informing the ITU of our work activities. In this previous correspondence, we indicated that we would be pleased to inform the ITU of our progress in the development of documents on software defined radio, and to offer the Forum's views on SDR as work on SDR progresses within Working Parties of each organiazation.

The Forum is aware of Question 230/8 on software defined radio that is being addressed by both Working Parties 8A and 8F in Study Group 8. We have also seen the progress made on the deliverables of WP 8F on Technology Trends and have determined that the current work and deliverables of the Forum are relevant to these activities in WP 8F.

Consequently, the Forum offers a Contribution Document(white) for consideration of ITU-R Working Party 8F at their September/October 2002 Geneva meeting, the material included in Attachment A. Given our understanding of the work within WP 8F, we believe this material will assist in the development of deliverables related to Question 230/8. While principally focused on the WP 8F work, we believe that this material may be of interest to WP 8A also. We ask that you would appropriately direct this material to the relevant Working Parties for their consideration.

The Forum believes it can continue to have a role in bringing industry and regulatory perspectives on software defined radio to the ITU-R and to the relevant standards organizations. The Forum believes that this will assist in unifying the work and help bring a global perspective across these international organizations. This would help ensure that the global aspects of SDR and regional incorporation of SDR specific technologies into radio system standards and technology implementations are closely aligned.

We offer an invitation to the members of the ITU to join in the Forum activities. Please refer to http://www.sdrforum.org for details of scheduled meetings and deliverables.

The Forum itself, and our members, many of which are also participants in WP 8F offer our support to the WP 8F work to progress the activities on SDR related deliverables.

Sincerely,

Allan Margulies
Chief Operating Officer
Software Defined Radio Forum

Attachment A: "Working Document Towards Preliminary Draft New Recommendation Software Defined Radio And Related Technologies M.[IMT-SDR]

cc Mr. Colin Langtry

INTERNATIONAL TELECOMMUNICATION UNION

RADIOCOMMUNICATION STUDY GROUPS

Document 8F/
September 2002
English only

Received: September 2002

Subject: Question ITU-R 229/8 and 230/8

VISION
RTECH
AD HOC WORKPLAN

SOFTWARE DEFINED RADIO FORUM

WORKING DOCUMENT TOWARDS PRELIMINARY DRAFT NEW RECOMMENDATION SOFTWARE DEFINED RADIO AND RELATED TECHNOLOGIES M.[IMT-SDR]

1 Introduction

Attachment 3.5 of the Chairman's Report from the 8^{th} WP8F Meeting (Document 8F/728) is the Working Document Towards a Preliminary Draft New Report on Technology Trends. It is the purpose of this contribution to provide views of the Software Defined Radio Forum regarding the software defined radio portion of this Technology Trends Report.

The Software Defined Radio Forum[1] (SDRF) is a non-profit organization comprised of approximately 100 corporations from around the globe dedicated to promoting the development, deployment and use of software defined radio technologies for advanced wireless systems. The SDRF has been following the work of the ITU-R WP 8F though member companies who are also ITU Sector Members. The Forum is encouraged by the prominence given to software defined radio by the ITU-R as illustrated by the fact that there is a separate Question on software defined radio that has been jointly assigned to Working Party 8F and Working Party 8A. The SDRF notes that a significant amount of material has been submitted to WP 8F on software defined radio for inclusion in the ITU-R Report on Technology Trends.

2 Discussion

The Editor's Notes on the first page of Attachment 3.5 to the 8^{th} Meeting Chairman's report states that if more detailed information is needed on a particular technology than can be provided in the Technology Trends Report, it should be put into a separate, new report. The second page of the current version of the Technology Trends Report provides a target number of pages for each technology trend topic. It is noted that for the software defined radio (SDR) topic, the number of pages allocated for SDR are much less than the number of pages already contributed on SDR. This

[1] More information on the Software Defined Radio Forum may be found at: www.sdrforum.org

is the case for both the body of the document (Section 3.2.1) and the supporting detailed information on SDR (Annex 7 of the Technology Trends Working Document).

The Software Defined Radio Forum believes that it would be beneficial to the members of the ITU and to the evolving wireless and software defined radio industries if a document on software defined is developed by ITU-R WP 8F that is separate from the Technology Trends Report. The advantages of this are:

- Software defined radio is a complex topic involving many aspects including radio aspects, network aspects, and spectrum efficiency considerations; a separate report is needed to describe these complexities.
- Proper treatment of software defined radio requires more pages than currently allocated in the Technology Trends Report.
- A separate document on software defined radio is most directly responsive to Question 230/8.
- The document on software defined radio will be of interest to regulators, wireless operators and service providers, manufacturers of radio systems, software developers, and component vendors.

The development of a separate document on SDR is consistent with the decision that has already been taken by the ITU-R to develop a separate document on adaptive antennas in response to Question 224/8. Ad Hoc Workplan should consider that this separation of the work on SDR is not new work; it essentially is a new and focused partitioning of work that is already ongoing.

At this juncture, the SDR Forum believes that the new document should be an ITU-R Recommendation rather than an ITU-R Report because there appears to be a need to recommend specific actions by administrations in regard to SDR. The start of a “Recommends Section” is provided in Section 5 of Attachment 1. This includes a list of topics that should be considered for the “Recommends” Section. Contributions against these “Recommends” topics are encouraged. The question of whether the SDR document should be a Recommendation or a Report should be revisited in future WP 8F Meetings depending upon the input contributions.

3 Recommendations

It is recommended:

1) that WP 8F develop a document M.[IMT-SDR] on software defined radio;
2) that the new document be in the form of a recommendation rather than a report;
3) that only a very brief summary of the SDR technology be retained in the Technology Trends Report, whilst the details on SDR be inserted in the new ITU-R Recommendation on Software Defined Radio;
4) that Ad Hoc Workplan consider:
    a) the proper placement of this work effort including the possibility of setting up a new drafting group for M.[IMT-SDR],
    b) and the time schedule for the completion of M.[IMT-SDR];
5) that Attachment 1 be considered as a basis for starting work on PDNR Software Defined Radio (IMT-SDR) during the 9th WP 8F Meeting. Specifically, it is recommended that:
    a) the information currently in Section 3.2.1 of the Technology Trends Report (Attachment 3.5 of the 8th Meeting Report) be reduced to only Section 3.2.1.1 General;

b) the information currently in Sections 3.2.1.2 through 3.2.1.6 of the Technology Trends Report be including in the new document M.[IMT-SDR];

c) that the outline of Attachment 1 be used as a basis for document M.[IMT-SDR];

d) that the existing text be inserted in the proposed new document as delineated in Attachment 1; and

e) consideration be given to including text on MEMS that is existing in the Technology Trends Report into the new document on SDR because the current text on MEMS includes SDR as an example.

Attachment: 1

ATTACHMENT 1

WORKING DOCUMENT TOWARDS

Preliminary draft new Recommendation (PDNR): Software Defined Radio and Related Technologies

[Editor's note: The outline below is the document structure proposed for this new PDNR. This new outline needs to be discussed during the 9th WP 8F Meeting (Geneva). The preliminary text in Section 4 (Considerations) and Section 5 (Recommends) is new text which should be discussed during the Geneva Meeting and should be regarded as being preliminary and subject to revision based on future contributions.

The text that appears in the Annex is text that has been carried forward from the 7th and 8th WP 8F Meetings (Queenstown and Ottawa). Specifically, the text that appears in Annex Sections 1 through 6 is from Document 8F/278 (8th WP 8F Meeting Report), Chapter 3, Attachment 3.5, Section 3.2.1.1. The text that appears in the Annex Sections 6 thorough 10 is text that appears in Annex 2, of Attachment 3.9 to 8F/623 (7th WP 8F Meeting Report) and was carried forward according to a decision taken in the Ottawa meeting. All of the text in the Annex, although it has been available to WP 8F participants for several meetings, is still subject to modification based on future contributions. Insufficient meeting time has prevented full review of this text which is important to this working document towards PDNR M.[IMT-SDR].

11.09.2002

1 Introduction

2 Scope

[Editor's note: The scope of this document needs further discussion. In Attachment 3.5 (Technology Trends Report) of Chapter 3 of Document 8F/728 (8th Meeting report), there is an editor's note stating the possibility of combing the Old Section 3.2.1 (software defined radio section) and old Section 3.3.1 (Terminal Architecture). In addition, there may be some value in combing the text on MEMS into this recommendation because the existing text gives SDR as an example.]

3 Related Recommendations

4 Considerings

[Editor's note: The following are example "considerings" and "notings" that are provided as a means of stimulating debate and future contributions.]

The ITU-R

considering

a) the information on software defined radio provided in Annex 1;

b) the need for global coordination of software defined radio technology to facilitate global circulation of terminals;

c) the need for global cooperation in the development of technologies that facilitate interoperability between commercial wireless systems and between commercial wireless systems and mobile systems used for emergency communications; and

d) that software defined radio technology is a technology that should be considered as one of the technologies that possibly could reduce the amount of spectrum needed for systems beyond IMT-2000;

noting

a) the software defined radio has network implications as noted in Annex 1;

b) that because of the increasing number of frequency bands and modes in commercial wireless systems, software implementation is becoming increasingly important thereby increasing the complexity of the wireless devices;

c) that software download to SDR-capable devices is of increasing importance to manufactureres and operators for software "bug fixes" and for implementation of new capabilities and services into both base stations and terminals;

d) that software defined radio is the subject of a vast amount of research;

e) that SDR-capable devices are starting to reach the commercial wireless marketplace;

f) that dynamic spectrum allocation/spectrum resource sharing is a subject of research, and

g) that regulatory agencies throughout the world are beginning to address regulatory issues related to software defined radio;

and further noting

a) that software defined radio is a technology that could help facilitate dynamic spectrum allocation/spectrum resource sharing; and

b) the difficulty in finding globally aligned spectrum for commercial wireless systems;

5 Recommends

a) that administrations carefully consider the potential benefits of software defined radio and encourage technical innovation by minimising regulatory actions that might hamper the development and deployment of SDR-capable devices;

b) .

c)

-
-
-

[Editor's note: Contributions are needed regarding recommendations on the implications of SDR-capable devices on:

- Dynamic spectrum allocation/spectrum resource sharing
- Spectral efficiency
- Interference management
- Network management
- Interoperability
- Security
- Need for additional research

These recommendations necessarily involve the network and not just the radio. The proposed recommendation will address all aspects of SDR-based communications systems, not just the radio itself.]

Annex 1

[Editor's note: The text in Section 1 through 6 below is from Document 8F728 (8th Meeting Report), Chapter 3, Attachment 3.5, Section 3.2.1. This material is presented with track changes intact to preserve original section numbering, etc.]

1 General

Software Defined Radio is a technology to provide reconfigurable radio systems, which aim at providing a common platform for multiple air interfaces, protocols and applications thereby increasing network and terminal capability and versatility by SW modifications (downloads). With the proliferation of open APIs, SW from different vendors can run on proprietary HW platforms.

Figure [3.2.1-1] illustrates the multi-layer aspect of Software Defined Radios. Examples of the benefits by Software Defined Radio are terminal upgrade (including "bug" fixes) via software download, service creation and service mobility, convergency of services and the associated adaptive use of spectrum, and scalable quality of service.

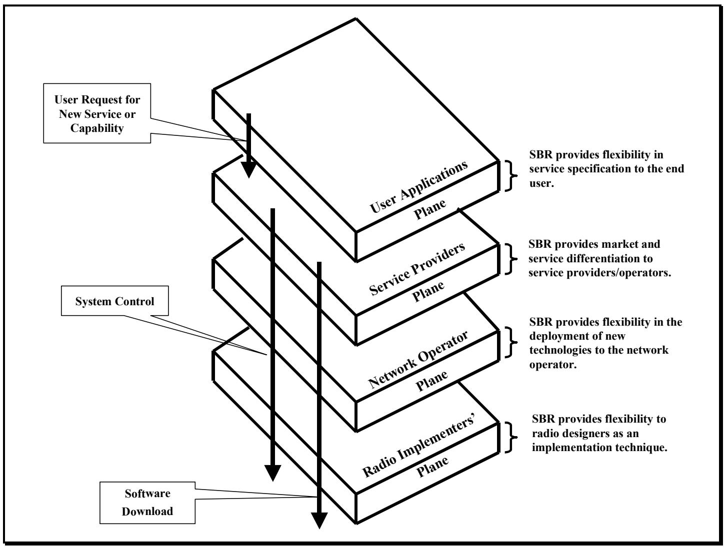

FIGURE 3.2.1-1

Multi-layer aspects of Software Defined Radio In the following the requirements for Software Defined Radios are explained. More information on the system architecture for reconfigurable devices may be found in Annex 6.

2 General Requirements for SDR

SDR addresses all communication layers and must therefore take into account demands of the individual communication profiles consisting of user, service, network and terminal profiles. Analysis of the needs and regulatory issues for reconfigurable equipment reveals a mapping of requirements and constraints onto a set of key system support functions and enabling technologies. These fall into three distinct groups:

- Creation and provisioning of services over converging networks and different radio access modes.
- User environment management and distributed processing framework supported by appropriate middleware(s).
- Radio reconfiguration control.

In the following three sections these three different areas are described in more detail:

3 Creation and provisioning of services over converging networks and different radio access modes

A key enabler for reconfigurable radio systems is the fast creation and provision of scalable services, developed independently of, and adaptive to the underlying network technologies, environment and traffic conditions, allows the convergence of fixed, wireless and broadcast networks. In conjunction with an appropriate management framework (distributed processing environment for reconfigurable terminals facilitated by e.g. a set of middleware) including capability negotiation and secure software download for reconfigurable terminals, services may be provisioned by adaptation to available resources, considering the terminal itself as a processing resource. This scheme requires the existence of a service description framework, possibly describing services in terms of reusable components and open interfaces, and a distributed processing control framework. The "Open Interface Service Provision" (OISP) is an example of such a scheme being developed under the 3G Partnership Programme (3GPP). A common terminal execution environment for *applications* namely MExE (Mobile Execution Environment), supports WAP, personal-JAVA and CLDC/MIDP Java environments independent of the access scheme (2G, 3G, cordless, wired), and is under development in 3GPP TSG-T2. Common to each application execution environment is a terminal capability negotiation mechanism and defined security domains through which applications may be downloaded and executed with appropriate access to terminal resources. Research work must investigate extensions to the MExE environment required to support software download of components and parameters *below* the application layer.

The management framework for reconfiguration must address the following functions:

- Service creation and service mobility.
- Secure software download.
- Scalable service provision with scalable QoS.
- Common execution environment.
- Consolidated billing mechanism.

4 User Environment Management and Distributed Processing Framework

These software concepts essentially provide the mechanisms to support requirements for user friendliness, transparent reconfiguration and distributed application processing. In computer networks, object-oriented technologies for distributed systems provide scalability and modularity, resulting in efficient software provisioning, faster deployment and bug fixing, higher flexibility and therefore improved cost efficiency. A framework is required to coordinate and manage communications and interworking within the distributed, object oriented environment. With the continuing convergence of computer and mobile communications technologies, such a framework could supply much of the support needed to realize the user-friendly, ubiquitous environment demanded by the future user. QoS management, reliability, mobility, security, radio resource management, distributed configuration management and user-preference agents may be considered as independent distributed objects operating within the overall network concept. The distributed run time system must support following functions:

- Secure end-to-end configuration negotiation between (distributed) parties with different domains of responsibility (user, service provider, network operator, manufacturer).
- Intelligent configuration (creation/update and secure management) of applications according to terminal and service capabilities and user preferences.
- Secure software download.
- Distributed processing for applications and configuration management.

A mobile framework for distributed processing could then be viewed as a virtual backplane supporting objects distributed between the terminal, Node B and RNC. It would be able to handle facets associated with a radio link between terminal-resident and network-resident objects, namely temporary disconnections, multiple simultaneous connections, terminal mobility, migration of objects between terminal and network via download (statically or dynamically, i.e. during run time), and should potentially support functionality such as:

- Maintenance of QoS for real-time applications.
- Safe interworking between disparate software components from different sources.
- Adaptation of applications to dynamic availability of resources (processing, bearer services).
- Managing handoff between air-interfaces where required services are only available to certain air interfaces.
- Concurrency and persistence, allowing the implementation of distributed processing and for the support of seamless handoff between different radio access schemes.

The virtual backplane concept may be schematically described as below, where objects for terminal management and user applications can migrate during run time. With migration of objects, mobile agents can be realized.

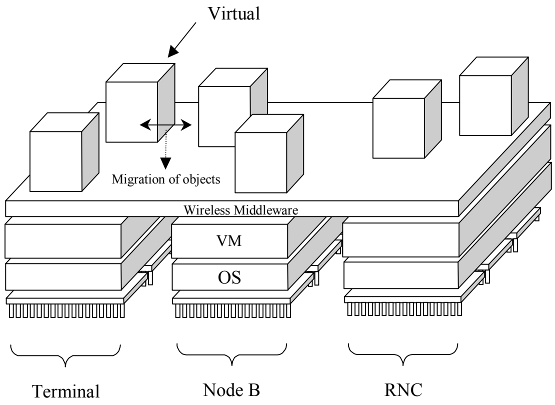

FIGURE 4-1

Virtual Backplane in a Distributed Processing Environment

5 Radio Reconfiguration Control

The functions described in previous section represent the key enablers for reconfigurable terminals to provide the connectivity, mobility, reliability, security and QoS required to access the potential of the evolved network scenario and thus to deliver the user requirements. Some terminal-centric solutions exist today and represent the state-of-the-art, however maximum benefit requires terminal/network cooperation and this is a central theme of system aspects research. Novel solutions will be proposed and evaluated in terms of complexity, performance, overhead, trade-off and feasibility through development of system models and simulation. In particular, the reconfiguration control has to reflect following functions:

- Radio access mode identification, blind and assisted.
- Radio access mode switching management.
- Simultaneous connection to multiple services.
- Secure software download including authentication, hierarchical capability exchange and integrity assurance.
- Efficient algorithms to realize flexible, robust radio access schemes.
- Flexible, reconfigurable terminal/base station software and hardware architectures.

6 Constraining Considerations

The concept of reconfigurable mobile communications by its very nature implies ever increasing flexibility, resulting in a potential system management nightmare. Research activities must constrain its research by careful consideration of realistic scenarios and constraints, with particular emphasis on:

- Regulatory and system integrity considerations.
- Privacy, anti-trust issues and security functions for reliable download.
- Complexity tradeoffs.
- Feasibility of migration from existing legacy solutions and implementations.

These may lead to considerations such as:

- Software download of radio-specific software (baseband, radio protocol stack objects, parameters) will be limited to manufacturer approved builds downloaded from a manufacturer's secure server to protect manufacturer's regulatory liability for system integrity.
- Terminal resource sharing between application and radio-specific software will be feasible only if terminal resources used by radio control software are adequately protected.
- Software updates not specifically requested by the user may adversely modify terminal behaviour due to incompatibility with other installed software.
- Anti-trust protection: Transparent introduction of software may hide or disable functions provided by a competitor's application.
- Use of intelligent user preference establishment and maintenance schemes to customize the terminal's behaviour must be secure such that user profile data is not accessible to untrusted third parties.
- Volume of downloadable software and over-air service negotiation for reconfiguration must be managed to avoid network impairment.
- Reconfiguration mechanisms must be backward compatible with existing radio access standards.

Regarding consideration of a distributed processing environment to support reconfiguration management aspects, the cost functions are the additional terminal resources (processing power, memory, IO) and over-the-air communication overhead (throughput, delay). Research will identify the framework functionality needed to support the key reconfigurable terminal system technologies, estimate key tradeoffs and examine feasibility.

[Editor's note: This text is from 8F/728 (8^{th} Meeting Report), Chapter 3, Attachment 3.5, Annex 6. A note in that annex states that from Section 6 to the end of Annex 2 of Attachment 3.9 to8F/623 (7^{th} meeting report) are to be inserted into the document. This has been done herein.]

[Editor's note: The carried over information from the 7^{th} meeting that is referred to in the above note is inserted below; major section heading numbers have been increased by 1.]

7 Frame work for Reconfigurable Terminals

Whereas the preceding chapters outlined the impact of SDR on the communication environment, we define here an overall system architecture defining the solution to the described challenges. Architectures for the support of SDR terminals are presented. The proposed functional and network architectures have been developed from a user-orientated perspective. This has been achieved by eliciting requirements from users and developing user scenarios. From these user scenarios, the key stages (or use-cases) for terminal reconfiguration are:

1) Identify alternative modes – in the geographic locality and estimate performance.
2) Negotiate most appropriate mode – based on criteria for selection (user preferences).
3) Download software modules – using the most appropriate mechanisms switch to new mode – reconfigure the terminal to the new mode.

System design roadmap resides on the following generic stages. Starting from Use Case scenarios, therefore stressing user-centric necessities, process requirements are derived supporting reconfigurability task. The previous section outlined the mayor steps of such a process. Those requirements are the basis to identify final functionalities within the process enabling terminal reconfiguration. Afterwards, system architecture is structured supplying the terminal with all the required entities providing aforementioned functionalities in a consistent manner. Thus, from the very beginning, the SDR System Aspects working group has clearly followed a Top-Down approach at system design time, which subsequent granular architecture eases upgrades and changes in radio dependent/independent functions.

Figure 7-1 depicts high-level Overall Functional Architecture and it shows main modular entities, each entity grouping specific functionalities and the interaction between them. It only gives a summarized feeling of what can be the final outcome of the research group, since the group is immersed on the refinement and improvement of the first general draft at actual stage.

Two main groups form the basis for the architecture. On one hand reconfigurable hardware and terminal resource system related part, depicted with horizontal lines; and on the other hand reconfiguration process control and configuration side, shown in clear grey, which is the core of this architecture and focus of the SDR System Aspects group. The later provides the terminal with the necessary functionality required during the reconfiguration process. Additionally, network implication during the reconfiguration process has also been addressed. It falls under the SDR terminal and network interactions section and those entities belonging to the field appear shadowed. Few more components appear in the architecture referring to actors who may trigger a reconfiguration process, namely User, Network Operator and Service Provider, and the Application, which is active part during the reconfiguration process as it may impose several requirements regarding RAT to be finally chosen.

Arrows drawn between entities represent interactions between those entities. They indicate either some kind of negotiation, a store/retrieve type of interaction if one of the entities represents a collection of data (depicted with wide vertical fringe), a kind of trigger, or a query operation.

Once the process requirements are understood, the main modules and their associated functionalities are presented following the reconfiguration process in chronological order. Accompanying Figures model entities by means of Unified Modeling Language (UML) at analysis stage, showing main class structures related to principal management modules involved throughout the reconfiguration process.

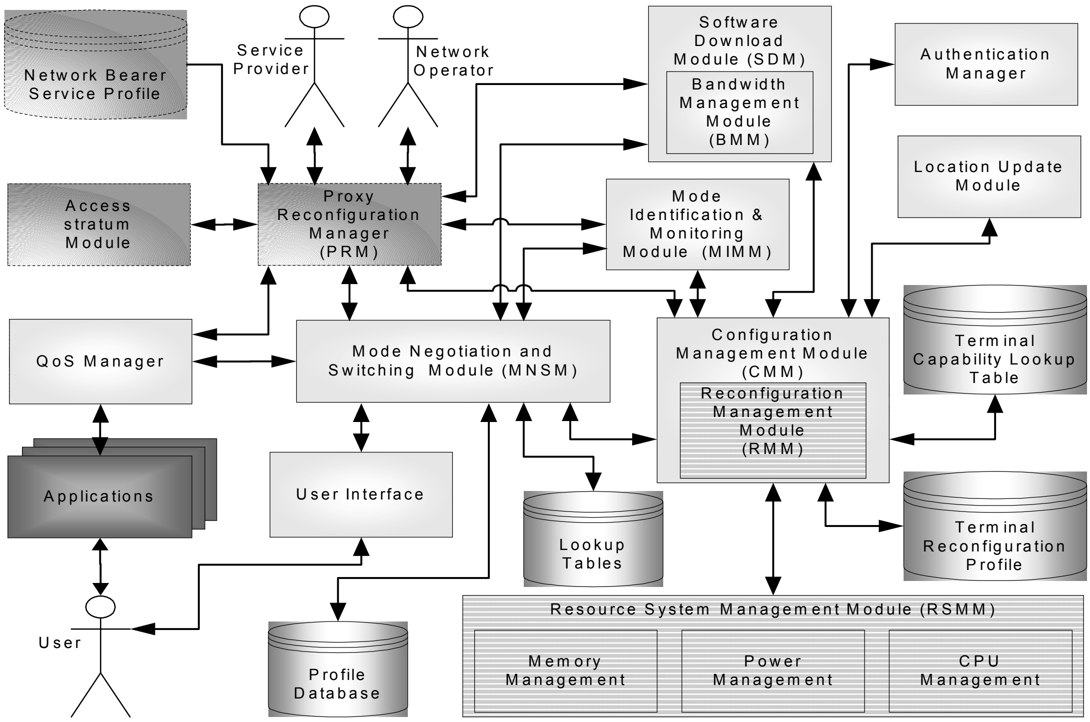

FIGURE 7-2

Overall Functional Architecture

8 Network Architecture Supporting Reconfigurable Terminals

An example for the network architecture supporting reconfigurable terminals is based on a network-centric approach (Figure 8-1) involving the association of Home Reconfiguration Manager (HRM), Serving Reconfiguration Manager (SRM) and Proxy Reconfiguration Manager (PRM). This architecture extends the classical cellular Radio Access Networks.

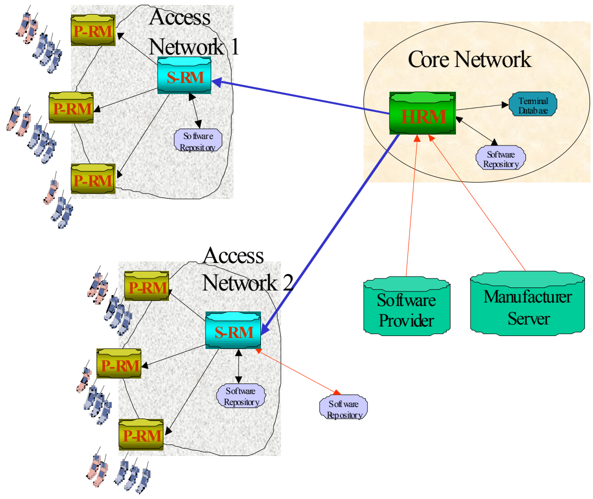

FIGURE 8-1

Reconfiguration Managers enlarging Classical Cellular Networks

Interactions between terminal and network are crucial as the available bandwidth on the wireless link is a limited resource that should be used for services rather than negotiations. Furthermore, resources on the terminal itself are usually also limited. In order to relieve the terminal from the burden of frequent interactions with network entities, information from the network could be generally obtained via the PRM, which is located in the radio access network. It serves as a proxy instance for negotiations with other network entities, in particular the SRM and the HRM.

9 Detailed Description of Frame Work for Reconfigurable Terminals

Software Defined Radio is considered as a key technology but a framework is needed how the interaction between the reconfigurable terminal and network must be defined. Such a framework for enabling a standardized negotiation procedure describes the interaction between network operator, service provider and user and is illustrated in Unified Modeling Language (UML) below:

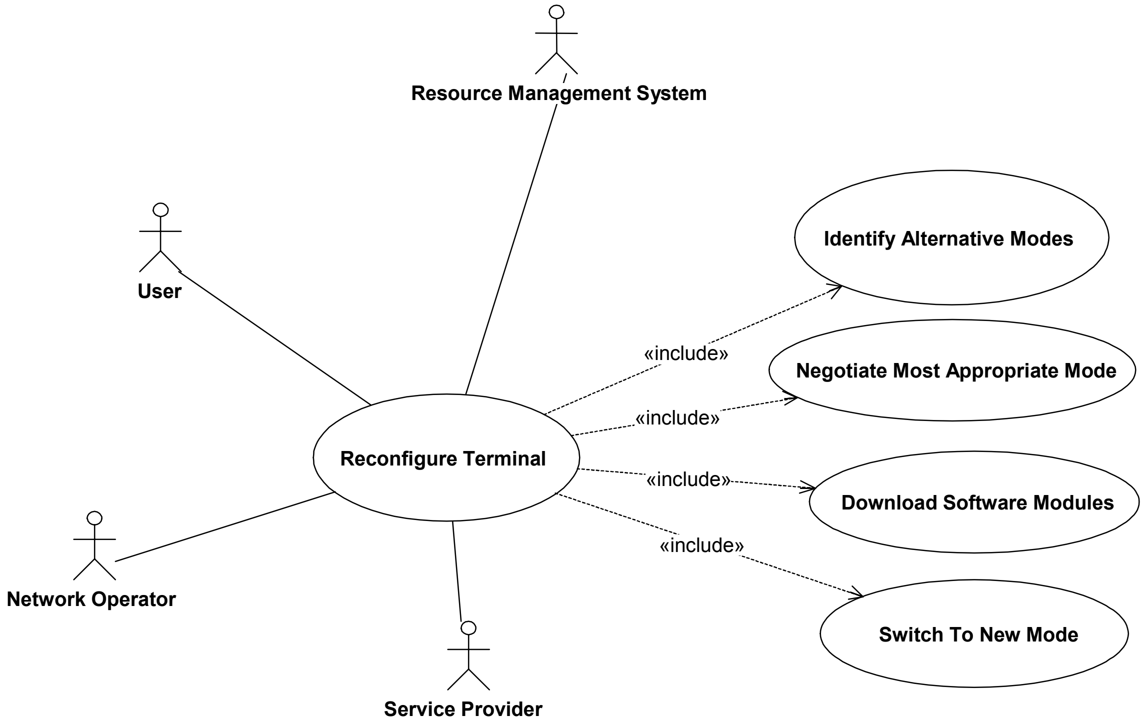

FIGURE 9-1

Reconfigurable Terminal Interaction

Derived from this top-level use-case diagram are defined detailed use-cases, class, collaboration, message sequence and state transition diagrams. UML is used to support the system architecture definition and the detailed design of modules in terms of functionalities and interactions. SDL is also used for specific modeling schemes.

Identify Alternative Modes

Identify Alternative Modes has two main subordinate use cases, which are *Unassisted Scanning* and *Assisted Scanning*, both of which can be controlled by the user. The U*nassisted Scanning* is only utilised when the user turns the terminal on and has no prior knowledge of available modes (as a fallback). The *Assisted Scanning* exploits information stored in the terminal or services in the network to provide information regarding alternative mode availability. The network operators, service providers and even other terminals can provide this additional information. The user can also have preferences for particular modes and this can also be taken into account during A*ssisted Scanning*.

Negotiate Most Appropriate Mode

Negotiate Most Appropriate Mode consists of two main subordinate use-cases, which are N*etwork Capability Negotiation* and S*ervice Negotiation*, (that uses A*ssess Terminal Capability* in order to decide whether the mode can be supported). *Network Capability Negotiation* utilizes network bearer service profiles and user preferences (which includes the cost and performance preferences) to decide whether a particular network is suitable. The S*ervice Negotiation* utilizes service requirements, availability and capabilities together with terminal capabilities (including the terminal resource availability) to decide which mode of operation is most suitable to support the required services. *Assess Terminal Capabilities* takes into account user preferences in terms of resource utilization (for example power consumption) and also the availability of software.

Download Software Modules

The main subordinate use-case for D*ownload Software Modules* is the actual performing of the S*oftware Download*, which includes the *Download Method Identification* and *Download Planning*. The *Download Method Identification* takes into account the terminal resource availability, user preferences in terms of urgency and cost of the mode change, network capabilities in the current mode (and alternative modes) and download service availability. This enables the most appropriate method of software download to be selected. The *Download Planning* takes into account the resource availability in the terminal, the user preferences for timeliness of download and cost, and the network loading to decide when to download the software.

The *Software Download* itself can then occur at the scheduled time from the selected service provider and using the selected network. The user preferences also need to be taken into account during the download especially if the demand for resources on the terminal become higher than anticipated. The user may also want to suspend the download and resume it later. Once the download has occurred, checks must be performed to ensure the integrity and validity of the software.

Switch To New Mode

The *Switch To New Mode* consists of *Activation* of software and hardware components that form the configuration to support the mode. This uses *Installation* and *Testing* and also includes a *Location Update* if a new network has been selected. The *Activation* of software must be performed in a controlled manner to ensure that the configuration of the terminal required for the new mode can be supported without conflict and without causing malfunctioning or abnormal operation. It is also necessary to deactivate software in the existing configuration of the terminal that cannot be supported simultaneously with the new configuration. The software module *Activation* must be authorized by responsible entities to ensure this high degree of integrity. The *Activation* of a new mode can be triggered by the terminal itself after performing mode selection, but can also be triggered by the network operator or user directly when necessary.

The *Installation* of the software into the correct location and *Testing* is performed via the platform specific resource management system.

10 Overview on the System Architecture

Subsequent design of detailed features, concerned mainly with negotiation strategies and decision making algorithms, are therefore carried out in parallel throughout design stages.

The module characteristics and interfaces shown in fig.2 are explained in the following:

10.1 Mode Identification and Monitoring Module (MIMM)

Discovers, identifies and monitors existing alternative modes within the constraints imposed by both terminal resources and the current mode. During the detection process the terminal will have to scan different frequency bands in order to detect available modes in the surrounding geographical area of the user. Therefore, the RF front-end must provide accurate dynamic behavior; i.e. be able to synchronize and retune without causing unpleasant side effects in the RF spectrum. Detection of alternative modes is very complex as a result of the constraints imposed by the current mode, in terms of the amount of "free time" available. Furthermore, if the terminal is in-session, the service must not be disrupted during the detection process, so the amount of time available is even more constrained. After this difficult task is completed and modes have been identified, monitoring of these modes is vital to ensure that a sufficient level of service and link quality is being offered before that mode can be considered as a potential roaming destination. Here again severe time restrictions are imposed by the current mode and by any active services. If the terminal can be assisted by some external entity (i.e. proxy, other terminals, third party) then the demands placed on the terminal by detection and monitoring activities can be alleviated to a certain degree, although external support cannot always be relied upon. MIMM has to determine what external support is available (if any), and the constraints of the current mode, from information provided by the Reconfiguration Management Module (RMM). It also has to determine, from information provided by the Resource System Management Module (RSMM) whether there are sufficient resources (battery power, processing power, memory, etc.) available on the terminal to be able to achieve the required mode detection and monitoring without adversely affecting the level of service in the current mode.

10.2 Mode Negotiation and Switching Module (MNSM)

This module guides the mode negotiation process. It checks service availability in the attempted mode, negotiates Bearer Services with the network and makes sure the terminal can provide desired performance levels in the attempted mode, regarding load of the system and link quality. Later on, and keeping in mind outputs from other modules a decision is made to change to the attempted mode or not. For decision making it is important to identify User preferences stored in the Profile Databases, link level quality provided by the MIMM, reconfiguration complexity given by CMM, time expected for software download provided by the Software Download Module (SDM), resource availability and user interaction (agreement) in case the User Profile is not set up in detail. Results of these negotiations are stored in Lookup tables, which should be used for potential future access to the same mode and network. They would save time and resources, as negotiation results would be probably still valid.

10.3 Configuration Management Module (CMM)

Controls the current and possible future configurations of the terminal, which includes the configuration of the system modules that control the mode switching, software download and mode identification and monitoring. In order to enable the configuration of different distinct parts of the terminal core software and hardware to be coordinated without restricting the flexibility of the implementation, a configuration management architecture with different domains of responsibility is proposed. Two types of entity are introduced to enable interaction between these domains of responsibility, which are domain managers and terminal agents. The domain managers are responsible for control of the interactions between terminal agents in different domains and provide generic configuration information that is required by all terminal agents. The terminal agents are responsible for performing specific configuration management operations, which include the retrieval of detailed information regarding current and possible future terminal configurations and controlling the reconfiguration of distinct parts of the terminal software and hardware.

Terminal agents interact with the RSMM in order to obtain information regarding the resources available before reconfiguration is performed. Each terminal agent is also responsible for requesting (via domain managers) other configurations to be activated or deactivated and for notifying other terminal agents (via the domain managers) of any change in the configuration status controlled by the terminal agent. In addition, the terminal agents perform the necessary reconfiguration management functions in the appropriate way. For example, falling under the Reconfiguration Management Module (RMM) section, one terminal agent could be responsible for the baseband section and could create active and shadow transceiver chains and control the switching between the two chains, while another could be responsible for the RF hardware section (both of these example terminal agents are likely to be within the manufacturer domain of responsibility). Furthermore, although not currently being addressed here, terminal agents responsible for protocol stack components may fall within the network operator domain of responsibility and control different parts of the communication protocol software, whereas terminal agents responsible for transport layer protocols and higher layer protocols may fall within the service provider domain of responsibility.

The configuration management module also provides information regarding the current and possible future modes to the mode switching module and other terminal modules. Therefore, it provides the mapping between modes (which are abstract representations of the RAT air interface and higher layer communication protocol combination) and the configurations that provide the support for those modes. This will include the resource consumption and reconfiguration time estimates for a given mode, which can be a very important criterion for making a decision in the mode switching process.

10.4 Proxy Re-configuration Manager (PRM)

The network provided supporting entity serves as a proxy instance for negotiations with other network entities, in particular the Serving Reconfiguration Manager and the Home Reconfiguration Manager. It provides information for Mode Identification and Monitoring, Mode Switch and Software Download processes and additionally for Configuration tasks.

It takes a crucial role in the mode negotiation and also for the software download task, since it provides the mechanism for network centric software download. PRM can function as an agent for autonomous service discovery and negotiations, reducing the (bandwidth) load and need for signalling over the wireless link, decreasing the workload (CPU and battery load) of the terminal. A direct connection of the proxy to a fixed (IP) infrastructure also saves cost and enables support for partial disconnected operation of the terminal. Thereby, PRM plays an additional function as an information broker for the terminal, which distributes data from different terminal entities to a variety of other entities and vice versa.

10.5 Software Download Module (SDM)

SDM contains the Bandwidth Management Module (BMM), which depending on several variable values calculates the optimum download strategy and sends it to the Software Download Module. SDM then takes charge of either downloading the software from a certain entity in the network, making the most of decentralised download schemes, or from the Lookup tables, i.e. libraries, which may contain the required module from a previous reconfiguration. It is also responsible for defining who can initiate, enable and disable software downloading.

10.6 QoS Manager

QoS Manager takes care of firstly mapping QoS parameters from user/application requirements to the levels of underlying technology components, which are formed by the Operating System (gathering both the software and the hardware platform) and Communication components; and secondly obtaining resources from the aforementioned components. Additionally it monitors status of service, if any, regarding user/application satisfaction level and dynamically adapts the requirements to potential changes on resource availability of each component.

Mapping of parameters, subject to mapping filters availability, is preceded by acquirement of parameters from several sources. Since each component may incorporate its own QoS control mechanism, the QoS Manager only addresses matters involved with the current and target Radio Access Technologies (RAT). Thus, the sources to be checked are restricted to the capabilities of the target RAT, compared to the current one, and the capabilities of the terminal in terms of its reconfigurable modules' performance in the new mode.

Afterwards, mapped parameters are compared against target ones (required by the application and set by the user, either on the User Profile or on demand). The comparison could be preformed at any level of parameter definition, no matter which parameters are mapped.

The QoS Manager uses the outcome information to obtain resources from specific components. With that goal in mind, it negotiates, reserves and adapts the available resources, and thus deploys the requested level of service satisfying as much as possible the user/application. Such procedures are already incorporated within the MNSM and thus, QoS Manager relies on MNSM for those purposes during Vertical Handover processes.

10.7 User Interface / Profile Database

User Interface and Profile Database dispatch the same type of information, which regards to user preferences for every single parameter user can set up. Profile Database, referring to the User Profile, acts as an agent for the user and keeps him unaware from underlying technology changes by making decisions upon the preferences set by the user previously.

User Interface takes a significant role whenever settings non-specified in the Profile Database are negotiated. Those cases demand user involvement for making a decision and therefore require user involvement via the User Interface.

Even though the System Architecture only shows one connection towards the MNSM, the User Interface is a basic module regarding user interactions during other actions within reconfiguration process. That is certainly true if the User Profile does not contain the specific settings demanded by each process, and therefore it cannot act like an agent for making decisions.

Examples of demanded parameters are the following ones. MIMM requires user interaction to search for certain modes related to specific services and QoS. SDM prompts the user for authorization on downloading software modules from differing sources and charging agreements for the downloading service. CMM requires user input to change terminal system configuration parameters, installation of downloaded modules and several conflicting settings as keeping records of previous configuration in detriment of saving memory.

The logic behind omitting direct connectivity between the User Interface and the mentioned modules resides on the fact that such interactions represent rather smaller amount of information exchange compared to the ones carried out with the MNSM. Thus, System Aspects group view is that remaining modules make use of an open link towards the User Interface, via MNSM.

It is worth mentioning that User Interface refers only to proposed System. It is assumed that external entities, as the Operating System, will require User Interface as well. Anyhow, such requirements are out of the scope of the system architecture and therefore deliberately omitted.

10.8 Access Stratum Module

Access Stratum Module contains all access specific functionality in each Access Network, which is subject to a certain RAT. It consists of the parts in the infrastructure and in the user equipment as well as the protocols between these parts specific to the RAT.

It provides real time status of resource availability in the access nodes, subject to cell load. Therefore, it trades resource allocation for potential connections via specific Radio Resource Management functionalities. Furthermore, it integrates signal strength measurement support for link quality assessment purposes, which are essential during Mode Switching decisions.

Additionally incorporates efficient mapping from the traffic attributes used by non-Access Stratum applications, given by dominating external network technologies, to the attributes of the radio access bearer layer of the access stratum.

10.9 Network Bearer Service Profile (NBSP)

The Access Stratum provides flexible radio access bearers characterised by parameters describing the type of information and QoS transported over the radio interface.

NBSP is a database compiling offered Bearer Services in each network. The catalogue is an essential source for Network Capabilities negotiation and Bearer Services QoS assessment. The list presents static information regardless of the cell status and therefore, although being a key parameter during Mode Switch negotiations, it is insufficient for Mode Switching decisions.

The database is controlled and subsequently updated by the Access Stratum. Appropriateness of distinguishing it from dynamic information, available from Access Stratum, made it to be represented separately from the Access Stratum Module for sake of clarity.

10.10 Authentication Manager

The Authentication Manager is in charge of the wide plethora of actions related to security during a reconfiguration process, such as authentication, authorization and accounting (AAA). It provides functionalities to handle security procedures prior to proceeding vertical handovers. Thus, Corporate to Public Networks handovers are possible by means of Virtual Private Network (VPN) negotiation methods.

10.11 Location Update Module (LUM)

Location Update Module supports mobility for reconfigurable terminals changing between different modes; there will be interactions between the mobility management functions of different networks.

Thus, it incorporates procedures for inter-working of existing protocols and numbering methods. Procedures regard to managing subscriber location data whilst maintaining confidentiality aspects. Since each network incorporates different means to perform with Location Update process, LUM relies in network side additional entities supporting seamless roaming.

The architecture definition within LUM has identified a number of interfaces between the main system components. These interfaces are described further in this section.

10.12 Configuration Management Module Interfaces

These are interface classes for the configuration management module. They consist of interfaces from the other components in the system and from user, network operator, service provider and manufacturer applications. The different types of interface (sub classes) determine which domain managers ultimately receive the requests and notifications from the various system modules.

Users of the interfaces are:

1) Software download module – for requesting information regarding different modes.
2) Mode identification and monitoring module – for requesting measurement reporting.
3) Mode negotiation and switching module – for requesting the capability, availability and resource implications of different modes and for actually requesting mode switching.
4) Resource system management module – for notification of low power conditions.
5) Proxy reconfiguration manager – for requesting the capability, availability and resource implications of different modes and for actually requesting mode switching.
6) User – for requesting information about different modes and configurations (via the mode negotiation and switching module).
7) Network operator, service provider and manufacturer applications – for requesting information about different configurations and performing configuration changes.

10.13 Proxy Reconfiguration Manager Interfaces

These are interface classes for the proxy reconfiguration manager, which is a network resident entity. These interfaces allow negotiations to take place in the network on behalf of the terminal in order to decide whether terminal mode switching should occur. The users of the interfaces are:

1) Service provider – to enable the setting of policies and request mode switching within the service provider domain.
2) Network operator – to enable the setting of policies and request mode switching within the network operator domain. This can include the setting up of network bearer service profiles.
3) MNSM – to enable the retrieval of bearer service profiles and other cost information.

10.14 Mode Negotiation and Switching Module Interfaces

The mode negotiation and switching module interfaces are to allow other system modules or user interaction applications to request a change of mode. The users of the interfaces are:

1) Proxy reconfiguration manager – for instructing mode changes and update of cached data.
2) Software download module – for mode change requests.
3) Configuration management module – for notifications of changes in configuration.
4) User – for all user interaction with the system for requests to change mode, suspend mode identification and monitoring, download software (including suspension and resumption) and obtain information regarding the terminal configuration.

10.15 Mode Identification Module Interfaces

The Mode Identification and Monitoring Module interfaces enable other system modules to obtain information about possible alternative modes of operation. The system modules that use the interfaces are:

1) Mode negotiation and switching module – for requesting information about available modes and the likely performance of the modes.
2) Configuration management module – for notification of changes in mode.
3) User – to enable the suspension and resumption of mode monitoring operations (via the mode negotiation and switching module).
4) Proxy reconfiguration manager – for requesting information about available modes and the likely performance of the modes.

10.16 Software Download Module Interfaces

The Software Download Module interfaces enable other system modules to request the downloading of software and to notify the SDM of changes in configuration. The system modules that use the interfaces are:

1) Configuration management module – for requesting software download.
2) Mode negotiation and switching module – for requesting software availability and time required (and resources consumed) for download of software.
3) Proxy reconfiguration manager – for requesting software availability and time required (and resources consumed) for download of software.
4) User – to request information regarding the software available and also to request the downloading of additional software and control of the download process (via the mode negotiation and switching module).

10.17 Resource System Management Module Interfaces

The resource system management module interfaces enable the reconfiguration management modules (within the configuration management module) to request information regarding the resources of the terminal.

10.18 Authentication Module Interfaces

The authentication manager interface enables the configuration management module to authenticate the sources of requests and notifications.

10.19 Location Update Module Interfaces

The location update module interface enables the reconfiguration management modules within the configuration management module to notify the LUM when a change in the mode has occurred that requires a location update to be performed.

10.20 Access Stratum Module Interfaces

The access stratum module interface enables the proxy reconfiguration manager to obtain information about the terminal that is held in the network and is specific to the access network technology.

Reconfigurable terminals must work with different radio access technologies. Therefore, there needs to be a method of comparing different radio access technology parameters. In future standards a clear split between access stratum and non-access stratum (or core network) is likely to occur. By this, all radio specific functions are kept within the radio access network, so the core network is actually independent of the radio access technology that is chosen to be used.

10.21 QoS Manager Interfaces

The QoS manager interfaces enable the PRM and MNSM to request information regarding the QoS requirements and availability.

QoS Manager information is used both for mode negotiation and mode switching decision making. One of the requirements in mode negotiation would be when a mode supports the required QoS (user and application). Moreover, if the actual mode does not provide acceptable quality of service over a given period, and further negotiations to decrease QoS requirements or to increase system resources (QoS renegotiation) are unsuccessful, a mode switching decision might be triggered.

QoS is a very subjective attribute that depends on the users perception of quality. Users may sense a different quality of service for the same application even if the same bearer attributes are provided by the system. The existing interface between applications and the QoS manager allows both applications and users to provide feedback on actual QoS, e.g. request higher resource reservation.

10.22 Terminal Centric Deployment

A terminal centric deployment assumes that all of the system modules are deployed in computational units within the terminal. In this type of deployment it is assumed that there is no need for interaction with a proxy reconfiguration manager in the network in order to perform reconfiguration of the terminal. The computational units may reside on the same or different processors within the terminal and may be processes, process threads or any other form of computational unit.

A user scenario will be used to illustrate the operation of this deployment example. Taking the first user scenario as an example:

1) When the user pauses the download and undocks the terminal, the MIMM is requested (via the MNSM) to enhance mode monitoring, as there are no active sessions. This means that the MIMM can request an enhanced scanning mode to rapidly detect and monitor different modes of operation.
2) Modes are identified by assisted scanning and the available mode information (held in the CMM) is updated. This request is authorised by first utilising the AM to authenticate the source, and the permissions for the source entity held in the CMM.
3) The MNSM is triggered to select the most appropriate mode. Information regarding the terminal capabilities in the current mode, together with the performance estimates and resources available in alternative modes are requested from the CMM, which in turn forwards the requests to the corresponding terminal agents. This includes an estimate of the time taken and resources consumed during the reconfiguration process.
4) Detailed information about the terminal capabilities and the ability to support configurations corresponding to the alternative modes are obtained by forwarding requests to terminal agents responsible for different aspects of the configuration required to support the alternative modes of operation. For example, alternative modes can require reconfiguration to take place from the physical layer right up to the network layer or even higher, which is likely to fall into different domains of responsibility under the responsibility of different terminal agents.
5) Service and network negotiations take place utilising the user preferences and the currently running application QoS requirements (obtained from the QM), to enable the decision on the most appropriate mode to be made.
6) The request to change mode is made to the CMM. The request is forwarded to the appropriate terminal agent. The reconfiguration can then take place in the correct sequence from physical layer upwards.
7) The mode change may require software to be downloaded with a request being made to the SDM. Successful completion of the download is notified to the CMM.
8) Finally, the terminal is in the new mode of operation and the relevant entities (MIMM and MNSM) are informed.

10.23 Network Centric Deployment

In a network centric deployment, a proxy reconfiguration manager deployed in the network performs the majority of the negotiation functions on behalf of the terminal. This enables the terminal functionality to be simplified at the expense of more complexity within the network.

Taking the second user scenario to illustrate the operation of this deployment example. This time:

1) The user inserts direct media containing software for many different modes of operation. The CMM is informed (via the MNSM) that the new software modules are available.
2) MIMM is triggered with the terminal having no active session and so the modes are identified by enhanced assisted scanning and the available mode information (held in the CMM) is updated.
3) The MNSM is triggered to select the most appropriate mode. As this is a network-centric deployment (and there is no current mode of operation), the user must manually select the required mode from a list of available modes.
4) The request to change mode is made to the CMM. The request is forwarded to the appropriate terminal agent. The reconfiguration can then take place in the correct sequence from physical layer upwards.

5) The terminal is in selected mode of operation and the relevant entities are informed (MIMM and MNSM). Now the information contained within the proxy reconfiguration manager must also be updated.

6) When an incoming call arrives it first triggers the selection of most suitable mode in the proxy request module within the PRM.

7) Information regarding the terminal capabilities in the current mode, together with the performance estimates and resources available in alternative modes are requested from the proxy CMM within the PRM. This includes an estimate of the time taken and resources consumed during the reconfiguration process.

8) Detailed information about the terminal capabilities and the ability to support configurations corresponding to the alternative modes is obtained.

9) Service and network negotiations take place utilising the user preferences to enable the decision on the most appropriate mode to be made.

10) The request to change mode is made to the proxy CMM within the PRM. The request is forwarded to the actual CMM using the current mode of the terminal, which then passes on the request to the appropriate terminal agents. The reconfiguration can then take place in the correct sequence from physical layer upwards.

11) The terminal is in selected mode of operation and the relevant entities are informed (MIMM and MNSM). Now the information contained within the PRM must also be updated.