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Classmarks for reconfigurable terminals

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***Abstract*—Even if the topic of classmark definition is not a new concept per se, it is to provide the definition for reconfigurable terminals. The introduction of reconfigurability adds several planes of parameters that can be included in the classmark compared to SOTA definitions. These parameters are to be grouped and a set of them chosen for the terminal classmark definition in order to allow transmitting a first characterisation of the terminal to the network in an efficient manner including terminal reconfiguration capabilities and required network support. The considerations made in this document reflect one possible approach regarding the area of Reconfiguration Profiles and terminal capabilities.**

***Index Terms*—Terminal Reconfiguration, Reconfiguration Classmark, Terminal Capabilities, Reconfigurability Levels**

Introduction

THERE are various scenarios for reconfiguration in cellular networks. In the different scenarios that are listed in this contribution, the reconfiguration of a terminal can be either initiated by the terminal itself or by different stakeholders on the network side.

Classmarks for reconfigurable terminals go beyond the state of the art definition that can be found for well-known systems (e.g. UE capability in 3GPP or GSM) since it covers several aspects such as hardware capabilities, software capabilities, reconfiguration capabilities, etc.

The first goal is to analyse and define which terminal characteristics are to be considered as part of these capabilities. Once they have been defined, they will be grouped in order to define an optimal communication mechanism between terminal and network. Reconfiguration classmarks will provide an efficient way to minimise the amount of information transmitted regarding terminal capabilities. The information can be transmitted at different stages, for example, a general terminal class when the terminal connects or camps in a new RAT and further information when a session initiates or when a handover is foreseen. Based on this information, it should be possible to derive which level of support does the terminal expect from the network for the different reconfiguration stages.

This contribution is based on the research work done in the E2R project [1].

Reconfiguration Scenarios

The reconfiguration of a terminal could take place in different ways and in different parts of the terminal involving different reconfiguration actions. In the simplest case a change of operational parameters in the terminal software is needed. In other situations DSP / FPGA microcode that is available in the local memory of the terminal is installed. But there are also scenarios where the required software is not yet available on the terminal and therefore has to be downloaded from the network before it can be installed.

Reference [2] defines the following reconfiguration:

Handover between different RATs

The surrounding heterogeneous network environment offers different access

technologies to the terminal. There are different reasons that can trigger the terminal to decide for a handover and to select another RAT. These reasons comprise, but are not limited to, the start of a new service, the moving terminal leaving the current network, the detection of a new network, the user's decision for a better bandwidth and QoS, a new RAT proposed from the network to the terminal.

In any of these cases the terminal and the network exchange information on the available surrounding networks and their capabilities. Based on the retrieved information the terminal selects an appropriate RAT for a handover. To process the handover to the new RAT the terminal reconfigures one of its radio chains to the new RAT.

Multi-homing

There are various reasons why a terminal shall be reconfigured to use multi-homing. The reasons comprise the pure increase of the transfer capacity as well as using different services via different access technologies and network operators. In all these situations the terminal is reconfigured to use two radio chains to access two different networks, which may use different access technologies.

Service adaptation

If the bandwidth or QoS of the current connection changes or if the terminal processed a handover to another RAT with a different bandwidth or QoS, running services and applications that are sensitive to the change in the quality of the connection are notified. The services and applications will now adapt to the new quality of the connection. An AV streaming application will change the stream quality corresponding to the new transfer capacity of the connection, i.e. the picture size, colour depth, frame rate or even the codec will change.

Installation of new radio/protocol software

The software for a new radio access technology is installed when the terminal wants to utilise or handover to a RAT that is not yet supported on the terminal. In that case the terminal installs new software modules in the reconfigurable modem hardware of the respective radio chain. Furthermore it also replaces the protocol stack for the respective radio chain.

Installation of software for new services

New services can be offered to a terminal either if the service provider introduces the new service or if the terminal hands over to a different network type or operator/service provider. In all these cases the network will inform the terminal about the availability of the new service. If the user of the terminal agrees to use the new service, the terminal downloads the software that is required for this service and installs it.

Besides of a new service an application on the terminal could download and install extension modules on demand, when they are needed. Furthermore new applications can be downloaded and installed, if the user decides to use them.

Customer care and software upgrade

A terminal or software manufacturer offers a new version of its software to the customers. This new version can either be an enhancement of functionality or a maintenance update to fix bugs and increase stability. All parts of the terminal software from DSP microcode to user applications can be updated. Different ways for the initiation of this scenario can be distinguished. The manufacturer can notify the terminals about new versions of a software, the user can search for new versions and especially in case of maintenance updates the manufacturer can instruct the terminal to download and install the new software version. In the other cases the user decides and initiates the download and installation of the new version.

Terminal Capabilities

Various capabilities of terminals can be distinguished which allow or restrict a certain degree of terminal reconfiguration. Depending on the terminal capabilities a terminal reconfiguration may require

additional support from the network reconfiguration management and network equipment. There is a large number of different elements that can be considered for capability description in reconfigurable terminals. Among others hardware, software and reconfiguration capabilities as well as different mode support are distinguished.

Hardware Capabilities

The main hardware capabilities of a terminal are the number of radio chains that the terminal hardware provides. On the hardware side a full radio chain consists of a receiver and a transmitter. It is assumed that a terminal has at least as many receiver as transmitter chains. On the other hand it is possible that a terminal shares one transmitter chain with multiple (in most cases two) receiver chains. The number of radio chains gives a first indication of the reconfiguration capabilities of the terminal but also of the support it requires in order to perform the reconfiguration.

The following possible combinations of receiver and transmitter chains are considered as important from the viewpoint of reconfigurability:

Receiver chains >= Transmitter chains	
1	1
2	1
2	2

Table 1: Number of receiver and transmitter chains considered for reconfigurability

For reconfigurability considerations all combinations with more than two receiver and transmitter chains support at least the same reconfigurability as a terminal with two full radio chains.

Frequency-Agile Capabilities

The frequency-agile capabilities define the ability of terminals to operate in several radio frequency bands for one or more radio access systems. Enhanced system functionalities envisaged in E2R in terms of detecting and negotiating unused areas of spectrum for a group of users motivate the definition of this capability.

Figure 1 depicts a classification of frequency-agile terminals. Currently, the switching to another carrier frequency can be under the network control and requires the gathering of terminal classmarks by the network. In the future (5 to 10 years), the degree of intelligence of terminals is assumed to increase where cognitive radio terminals will autonomously detect unused areas of spectrum [3], [4]. The full potential of these new types of radios will be reached when they will be built on top of configurable RF front-ends that adjust their operating parameters to meet various regulatory requirements and standard specifications.

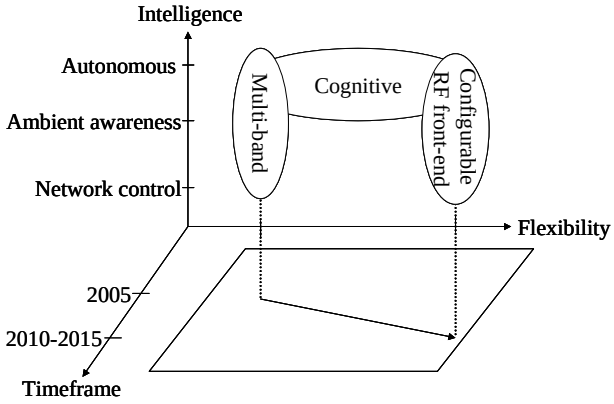

Figure 1: Classification of frequency-agile terminals

Terminal Modes

Terminal modes categorise the number of Radio Access Technologies that can be used by a terminal. A terminal can be basically classified into single-mode, multi-mode and multi-homing terminals. Single-mode terminals offer only one radio chain supporting a single technology. On the contrary, multi-mode terminals support two or more RATs but can only use one at a given time. Multi-mode terminals can consist of one configurable radio chain or of several radio chains configurable or not. Whereas multi-mode terminals can only connect to one RAN at a time, multi-homing terminals allow for simultaneous connections within different access networks. Minimum requirement in terms of hardware is two receivers and one transmitter if network support is available. Otherwise two complete radio chains are mandatory.

Single-mode

The terminal supports only one mode, i.e. it can be connected to only one RAN at a time.

Single-mode terminals have only one radio chain and support only one RAN. The radio chain of these terminals cannot be configured or parameterised in order to support another RAN.

Multi-mode

Multi-mode terminals support more than one mode, but can use only one mode at a time. This type of terminals is characterised by one of the following:

- One configurable radio chain that can be parameterised to support related RANs
- More than one radio chain (i.e. 2 receivers and >= 1 transmitter), but only one radio chain can be connected to a RAN at a time

Multi-homing

A multi radio chain terminal has multiple network interfaces and IP addresses allowing multiple simultaneous connections to different RANs. The traffic from and to the terminal can be split into multiple connections in order to utilize the bandwidth of the available connections, e.g. to increase the download speed.

Multi-homing is possible with terminals that support at least two receivers and one transmitter. Of course having as many transmitters as receivers requires less network support for multi-homing because the terminal can directly transmit to each RAN it is connected to. This is referred to as full multi-homing.

Dependencies of Reconfiguration Capabilities

Depending on the number of radio chains in the terminal and on the terminal modes, different capabilities can be offered by the terminal.

Mode reconfigurability specifies that a terminal can change the RAT that it uses to build a connection. It may be supported on the fly while the terminal is running or may require a restart of the terminal or the terminal services.

The handover between two access technologies and RANs is considered as seamless, if the user of the terminal does not notice this automatic handover. This means that from the user's viewpoint no service has been interrupted and no losses occurred. If the terminal cannot manage seamless handover on its own, this can require a certain support by the network reconfiguration manager and network equipment.

Seamless terminal controlled soft handover does not require special support by the network instances. The terminal has full multi-homing support and builds up a connection to the target RAN while retaining the existing connection to the current RAT unchanged. After the connection to the target RAN is established, the terminal starts the services that are running on the initial connection for the target connection in parallel. When all the parallel services are running, the terminal step by step switches from the initial services to the services using the new connection. Then the old services can be terminated and the old connection is broken.

Terminals that do not support full multi-homing, e.g. because they do not have two receiver and / or transmitter chains, require support by the network reconfiguration management and the network equipment in order to achieve a (from the user viewpoint) seamless handover from one RAT to another.

A soft handover is characterised by an automatic and smooth handover between two access technologies and RANs, without any user interaction. The terminal requires multi-homing capability, because it will already connect to the new RAN while the connection to the old RAN is still valid. During that period the terminal receives information via both connections simultaneously.

Terminal Configuration Profile

Another aspect related to the reconfigurability concept is the definition of further and more detailed terminal attributes, which are taken into account during the reconfiguration process. These attributes might be related to different reconfiguration actions and might be transmitted to the

network if they are needed to improve the reconfiguration process.

This set of attributes is part of the terminal profile. In general, the terminal profile is considered as a format for information storage.

From the terminal point of view, the configuration profile may be integrated within the User Equipment profile as dedicated components and attributes. Alternatively, it may be considered as an individual/special profile that will fully describe the operating capabilities and the current terminal configuration.

Based on the transmitted information, the network creates a profile reflecting the current configuration of the terminal and can also include detailed information on specific terminal reconfiguration capabilities. In this sense, the profile created by the network can be seen as a subset of the one maintained within the terminal.

Figure 2 illustrates a part of the configuration profile.

The **Hardware** entry describes the hardware components of the terminal that may be considered as reconfigurable, mainly as far as concerning their functionality. In this sense, the Hardware entry, initially, may be composed of:

- The Execution Environment which identifies the Execution Environment hardware components that are used specifically for execution of software components within reconfigurable User Equipment. Apparently, reconfigurable equipment needs reconfigurable hardware components. Such components may be multi-processor cores, reconfigurable logic, parameterised ASICs.
- The Hardware Limitations represents the working ranges of the physical components in the terminal. Examples of the defined attributes are the frequency range of the antenna; maximum transmitted power or receiving sensibility.

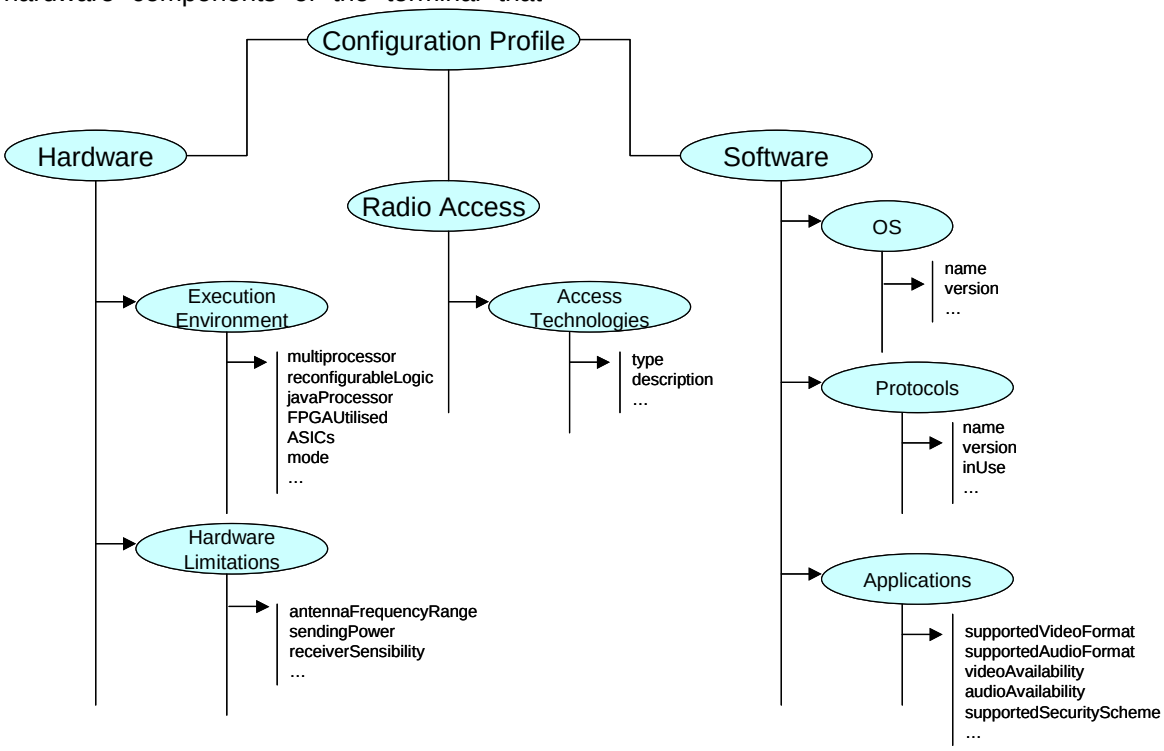

Figure 2: Terminal Configuration Profile

The **Radio Access** entry describes the different access technologies that are available at the terminal for communication purposes. These technologies could have been implemented originally in the terminal or be available as a result of a previous software download.

The **Software** component describes the parameters of the different software layers within the different radio access technologies. The Software entries defined within the Configuration Profile are the following:

- The OS entry that describes the Operating System
- The Protocol entry describes the available protocol components
- The Applications entry describes the application/service related information capabilities for the user equipment

Terminal Reconfigurability Levels

The reconfigurability of a terminal depends on the one hand side on the ability of the terminal to change its capabilities. This ability can vary from “no reconfiguration” to “fully dynamical reconfiguration”. In the latter case a standardised description of the new configuration or mode is enough for the terminal to implement the reconfiguration.

Another important issue is whether the reconfiguration of the terminal requires a restart of the terminal or if the terminal can stay online during the reconfiguration without interrupting running services.

Furthermore, the reconfigurability levels consider the different layers in the terminal where a reconfiguration can be required. The modem / hardware layer and the above lying software and service layers are distinguished here.

Based on these parameters reconfigurability levels will be defined and assigned to the terminal capabilities.

A reconfigurable terminal distinguishes different layers that can be reconfigured either individually or in combination. The following layers in a terminal can be reconfigured:

- Modem and Hardware Layer:
  Download, installation and configuration of DSP microcode for modem functionality, codecs and plug-and-play hardware extensions.
- Protocol and Driver Layer:
  Download, installation and configuration of protocol stack modules and device drivers.
- Operating System and Execution Environment Layer:
  Installation of update and enhancements
- Service and Application Layer:
  Download and installation of service protocols and software as well as additional applications that increase the functionality of the terminal.

A reconfiguration of the modem and hardware layer often is accompanied by a reconfiguration on the protocol and driver layer. It is not necessary that software is installed on both layers, e.g. if a new microcode for the modem is downloaded to the DSP, the existing IP protocol stack may only be parameterised to adapt to the new modem. In many cases service and application layer reconfiguration does not influence / require a reconfiguration on the lower layers, but in some cases it might be needed, e.g. special service protocol, driver and DSP microcode for a hardware codec.

Another aspect that needs to be considered for the reconfiguration levels is whether the reconfiguration (of one layer or the combination of multiple layers) requires a restart of the complete terminal, parts of the terminal e.g. the radio chain, only an application or if the reconfiguration is done seamlessly for the user / the connected networks.

The following lists various reconfiguration and restart aspects:

- Complete terminal restart (may be required in certain cases of hardware reconfiguration and changes in the operating system or execution environment)
- Radio chain restart (if the terminal has only one radio chain, this means that the current connection must be broken in order to complete the reconfiguration.)

- Application or service software restart
- Seamless reconfiguration without any service interruption (or restart)

Above-mentioned reconfiguration aspects are combined and result in the following reconfigurability levels that can be independently applied to each of the reconfiguration layers. Of course higher reconfiguration levels support the functionalities of the lower levels as well.

Static Reconfiguration

- No software modules can be downloaded and installed
- Reconfiguration is decided and selected by the user
- The terminal or the reconfigured layer / application must be restarted for the reconfiguration to take effect

Quasi-Static Reconfiguration

- Terminal dependent executable code can be downloaded and installed
- Reconfiguration is decided and selected by the user
- The terminal or the reconfigured layer / application must be restarted for the reconfiguration to take effect

Quasi-Dynamic Reconfiguration

- Terminal dependent executable code can be downloaded and installed
- Reconfiguration is decided and selected automatically based on policies
- Module download and reconfiguration can take effect without restarting the reconfigured layer / application; soft handover between old and new configuration

Dynamic Reconfiguration

- Standardised terminal independent description of the RAT or software module can be downloaded and the related reconfiguration can be implemented
- Reconfiguration is decided and selected automatically based on policies
- Module download and reconfiguration can take effect without restarting the reconfigured layer / application; soft handover between old and new configuration

	Static	Quasi static	Quasi dynamic	Dynamic
No software download	✓			
Download and installation of terminal dependent code		✓	✓	(✓)
Download and implementation standardised specification				✓
User decides and selects reconfiguration	✓	✓	✓	✓
Automatic policy based decision and selection of reconfiguration			✓	✓
Restart of terminal / reconfigured layer	✓	✓		
Seamless handover between old and new configuration (no interruption)			✓	✓

Table 2: Reconfigurability levels and their characteristics

Stakeholders

In a heterogeneous and reconfigurable network environment a number of stake-holders can be identified. Each stakeholder has its own view on reconfiguration and initiates other reconfiguration actions. The intention here is to provide an overview of the stakeholders that are relevant for reconfiguration and to briefly describe their reconfiguration interests.

Equipment manufacturer

The main business interest of equipment manufacturers in reconfiguration is that, having a common hardware platform for all markets makes it easier and more profitable for them to offer their equipment to all these markets. For the terminal manufacturer, reconfiguration is mainly related to the modem and protocol stack. Furthermore, the system software of the terminal can be updated and the terminal functionality can be extended. From the manufacturers point of view the reconfiguration of a terminal means

- Installation of new / different / optional software modules
- Changing of parameters and configuration information

Both types of reconfiguration can be

related either to one or multiple of the following parts of the terminal:

- Hardware related (e.g. DSP microcode)
- Protocol stack
- System software (operating system, applications, plug-ins, skins)

The equipment manufacturer initiates a reconfiguration when important updates have to be installed on the device. The terminal (software) itself will initiate a reconfiguration i.e. a download of additional modules (modem, protocol or application related) when it detects the necessity for these modules.

Network operator

In a heterogeneous network environment different network operators collaborate and have roaming agreements with each other to provide the optimum service to the mobile user. As a consequence a terminal distinguishes a home network (network of the own operator), visited networks (networks of partners collaborating with the home operator) and the enterprise network of the user's employer. In addition there may as well be private home networks.

In general the network operator's view on reconfiguration is to provide the terminal with the required support for new access technologies and the necessary configuration parameters for existing and new technologies in order to offer the terminal the best available connection within the own heterogeneous network structure. Sharing and balancing the load in the different networks of an operator is another topic for reconfiguration initiated by the network operators. There may be even a load sharing between different network operators.

For the home operator it is important to restrict the reconfiguration of certain home operator specific parts of the terminal when the terminal is not in the home network. These restrictions comprise all contract related software and configuration parts. Furthermore the home operator surely restricts the removal of contract specific software through other operators.

The visited network operator may provide additional access technologies and functionalities that he is supporting within his network environment. The same applies to the network operator of the user's employer, which might provide special in-house technologies and services.

Service provider

The interests of the service providers in reconfiguration are to make sure that the running services are not interrupted when the terminal changes protocol and access technologies. Furthermore the service providers want to offer new services as soon as possible to the terminals and their users. The application of new services to a terminal shall require only the contractual online acceptance of the user for the new service; all necessary installation must be executed automatically without user interaction. Services that are only available in certain networks shall automatically be configured when the terminal hands over to such a network.

3rd party Software manufacturer

3rd party software manufacturers interest in reconfiguration is to provide and sell new and updated software modules to the terminal in order to increase terminal functionality and stability. Furthermore optional modules may be downloaded and installed on demand.

User / owner of the terminal

The user and the owner of the terminal want their terminal to reconfigure in order to seamlessly handover between the different access technologies. Furthermore they want their terminal software to be kept up-to-date. Depending on the owner's preferences the terminal might use different strategies such as being always connected, always the best service or lowest cost.

Regulator

The regulator ensures that the essential RF parameters (central frequency, output power level, frequency band, out-of-band emissions) are within the regulatory permitted range. Therefore it is necessary that the regulator permitted values are informed to the terminal.

Table 3 illustrates which type of software the different stakeholders are expected to download for a terminal. Furthermore the minimum required reconfiguration level of the

related terminal reconfiguration layer is specified for the type of software download.

	Stakeholders for Various Types of Software Download					
Type of software download	**Regulator**	**Manufacturer**	**Operator**	**Service Provider**	**User**	**Min. required Recon-figuration level**
Application SW		**(X)**	**X**	**X**	**X**	**Quasi-static**
Radio SW controlling HW/RF parameters	**X**	**X**	**X**			**(Quasi-) dynamic**
Radio Standard specific	**(X)**	**X**	**X**			**(Quasi-) dynamic**
Operating system and drivers		**X**	**X**	**X**		**Quasi-static**

Table 3: Stakeholders of software downloads related to reconfiguration classes

Reconfiguration Classmarks

Reconfiguration classmarks are needed to inform a network about the reconfiguration capabilities of a terminal. The distinction of different types of terminal reconfigurability allows the instances in the network to offer the connected terminals the individually needed degree of reconfiguration support.

After a terminal identifies itself at a new network, it transfers besides other information its reconfiguration classmark. The reconfiguration management instance in the network stores the terminal reconfiguration classmark and decides based on it, which of the surrounding networks is suitable to be offered to the terminal as possible candidate for a handover. The terminal can use this information in its selection and decision process. When the terminal decides for network to handover to, the network reconfiguration management can deduce from the terminal reconfiguration classmark the required reconfiguration support that it must provide to the terminal for a smooth reconfiguration.

Reconfiguration classmarks describe the characteristics of a reconfigurable terminal. Hence the classmark has to contain a set of terminal capability information. This set of information can be completely transferred from the terminal to the network in one step or stepwise on demand. The latter approach is more efficient from the perspective of the amount of data transferred via the air interface. At the initial point of communication between the terminal and the network it is sufficient to inform the network about the reconfiguration class of the terminal. Additional information is transferred in a later phase when it is actually needed. If additional information is not needed, e.g. no connection is established or reconfiguration is not possible, it is not transferred at all.

Based on the reconfiguration levels defined previously, which are combined with the different reconfiguration layers, the following structure for the reconfiguration classmarks can be defined:

2 bits for the specification of the reconfiguration level of each of the four reconfiguration layers

4 bits to indicate if and which layers of a terminal are reconfigurable

Complete reconfiguration classmark:

```
a b c d | e f | g h | i j | k l |
```

The bits a to d indicate if and which layers can be reconfigured, a stands for the modem and hardware layer, b for the protocol and driver layer, c for the operating system and execution environment layer and d for the service and application layer. If the corresponding bit is “0”, the layer is not reconfigurable, if it is “1”, the respective layer is reconfigurable. The actual reconfiguration level of the layer is stored in the respective reconfiguration level bits for this layer. In the following the binary values map to the reconfiguration levels.

```
0 0 = Static
0 1 = Quasi-static
1 0 = Quasi-dynamic
1 1 = Dynamic
```

Use of Reconfiguration Classmark Information

The information defined in the previous sections is used at several instances related to the reconfiguration process. In a first

instance, the hardware capabilities and the terminal modes offer a first indication of the support that a terminal requires from the network side; varying largely from a single-mode terminal up to a dual radio chain full multi-homing terminal.

Usually, the first step in an intersystem handover is the so-called mode discovery and monitoring. This process may include a first filtering of the modes in order to provide only those the terminal can reconfigure to. For this purpose, information is required on the modes supported by the terminal but also on the terminal reconfiguration classmark at least for the modem part. If the modem allows at most only static reconfiguration, only those supported modes would be further considered.

Another possibility is that the discovery and monitoring process just provides the information on available networks without taking terminal information into account. In this case, the information would be required for the negotiation phase if it is to be done at the network side. This difference could lead to different strategies on how and when to transmit terminal classmark information. Even the decision on whether to perform negotiation locally at the terminal or externally by the network can be based on classmark information, either as an explicit parameter or implicitly based on the terminal mode and terminal status. This way, it can be assumed that single-mode terminals in connected mode would prefer the negotiation to be carried out on the network side while more advance multi-mode and multi-homing terminals would rather try to perform negotiation on their own based on information collected from the network.

Information on terminal modes can be used for mobility support purposes. Single mode or even multi-mode terminals will require of larger network support for the provision of transparent (lossless) handover, e.g. caching functionality, for multi-homing terminals, a network entity could be in charge of bi-casting the information to both RATs at the same time.

Conclusion

The aim of this paper was to define reconfiguration classmarks in order to support the communication between reconfigurable terminals and related network instances. The presented classmark definition provides an optimized mechanism for the communication between terminal and network. The reconfiguration classmark information is split into different sections and can be transmitted in portions when it is needed.

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