IEEE P1900.B: Coexistence Support for Reconfigurable, Heterogeneous Air Interfaces

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Abstract— This contribution presents and discusses the system concept approach which has been proposed by the European Integrated Project IST-E^{2}R II in the IEEE P1900.B Standardization Study Group (SG); it currently is under further elaboration in the framework of the follow-up IEEE P1900.4 Working Group (WG) whose Project Authorization Request (PAR) was accepted in December 2006. This effort targets reconfigurable (typically Software Defined Radio (SDR) based) networks and terminals in a heterogeneous wireless environment, with multi-homing capable terminals enabling the users to operate multiple wireless links simultaneously. In order to ensure backwards compatibility to legacy standards, the approach is to introduce three new building blocks into the (existing and/or evolving) heterogeneous landscape: i) A Network Reconfiguration Management module, ii) a Radio Enabler and iii) a Terminal Reconfiguration Management module. Within this paper, the key functionalities of these building blocks are detailed and discussed; it is furthermore outlined how the introduction of distributed decision-making concepts improves the efficiency of the heterogeneous system in terms of i) signaling overhead, ii) reactivity of user mobile terminals (MTs) and iii) numerical resource selection optimization complexity on the network side.

Index Terms— **Autonomic networking, cognitive networks, reconfiguration, software defined radio.**

I. INTRODUCTION

The IEEE P1900.B standardization Study Group (SG) discusses *Coexistence Support for Reconfigurable, Heterogeneous Air Interfaces* [1] in close cooperation with the European IST-E^{2}R II [2] integrated research project. In December 2006, the creation of the corresponding Working Group (WG) IEEE P1900.4 was approved. The goal is to work towards a harmonized cohabitation of multiple existing and evolving heterogeneous wireless radio standards. Based on IEEE P1900.1 work on Software Defined Radio (SDR) related terminology, IEEE P1900.2 contributions on Interference definitions in an SDR context, IEEE P1900.3 definitions on conformance evaluation and IEEE P1900.A's work on dependability issues [3], the IEEE P1900.B SG is working on architectural and protocol definitions enabling an efficient usage of the network capacity in a heterogeneous context as illustrated by Figure 1. With the follow-up IEEE P1900.4 WG creation indicated above, the proposals within this paper are currently under discussion in the group for acceptance as a base-line architectural representation in the standard. This effort is complementary to other beyond-3rd-Generation (B3G) system concepts such as 3GPP LTE (Long-Term-Evolution) [4-5] dealing with an evolution of 3GPP, IEEE 802.21 [6-7] proposing vertical hand-off related mechanisms, etc. In particular, 3GPP LTE and IEEE 802.21 are expected to provide means for efficient vertical hand-off between licensed and unlicensed band technologies as well as functionalities related to maintaining two links in parallel in order to access to different services in parallel (e.g., low-latency and low-data rate service for VoIP, high-data-rate moderate latency services for video-streaming, etc.). In contrast to these efforts, IEEE P1900.B is focusing on a wireless data network evolution where enhanced QoS (increased throughput, improved availability, etc.) is available due to reconfigurable multi-homing capabilities in the MTs maintaining multiple heterogeneous links simultaneously. In particular, the vision is that operators may increase the capacity of a heterogeneous cell by deploying a number of distinct radio standards. Finally, the network provides *policies*, to be understood as radio resource selection constraints (as illustrated in section IV of this paper), subject to which the MTs choose their resource selection strategies. If suitably chosen, these constraints will assure an optimum usage of the aggregate network capacity while each user device will optimize its radio resource selection strategy interpendently and with respect to its own criteria and operational characteristics.

The heterogeneous B3G concept applied within IEEE P1900.B in particular does not necessitate an entire redeployment of a new (4th generation or other) cellular
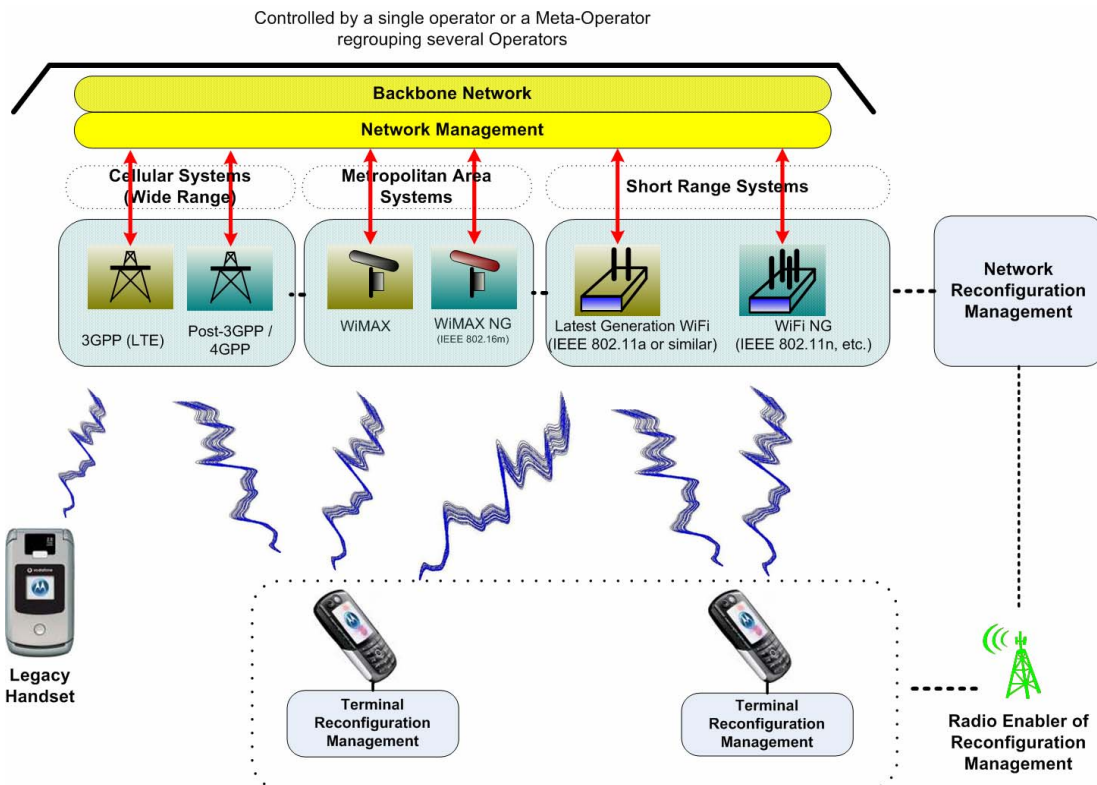
Figure 1. Distributed Architecture and building blocks enabling distributed decision-making: i) Network Reconfiguration Management, ii) Radio Enabler of Reconfiguration Management and iii) Terminal Reconfiguration Management.

system and allows a gradual, non-disruptive evolution of an existing wireless (cellular or other) infrastructure. In such a context, radio interface standards, such as 3GPP, GSM, the IEEE 802.x family, etc. are building blocks which will be efficiently controlled by a meta-standard approach defined within IEEE P1900.B. In this context, a key issue is the assurance of backwards-compatibility to the existing standards, since a modification of each single standard seems lengthy and quasi-impossible from a practical perspective. As a consequence, IEEE P1900.B introduces new building blocks which are transparent for legacy devices, but enable a more efficient operation for IEEE P1900.B capable ones: i) the Network Reconfiguration Management (NRM), ii) the Radio Enable of Reconfiguration Management (RERM) and iii) the Terminal Reconfiguration Management (TRM).

This paper is organized as follows. Section II presents a scenario relying on heterogeneity and distributed decision making functionalities, followed by Section III dealing with the generic IEEE P1900.B system concept introducing three new building blocks detailed within the subsequent three chapters; the Network Reconfiguration Management (NRM) entity is discussed in section IV, section V deals with the Radio Enabler of Reconfiguration Management (RERM) entity and section VI with the Terminal Reconfiguration Management (TRM) entity. A typical scenario is introduced in section VII while a conclusion finally follows in section VIII.

II. SCENARIO DEFINITION

With the goal to raise the main technical issues related to the field of distributed device reconfiguration management and network self-organization and –management, a system scenario on reconfigurable and autonomic communication systems for seamless experience is introduced. The scope of this scenario is to guide the introduction of respective functions that fall into the scope of the IEEE P1900.B group. In particular, the technical issues emerging from the scenario description may provide guidance to the detailed definition of the basic building blocks of the distributed architecture and corresponding high level signaling between these blocks. The following analysis presents this system scenario and addresses main technical issues tackled in the two different scenario phases. A more detailed description may be found at [14].

1. The network decides that a specific group of users and mobile devices should change RAT in order to distribute the load among resources as efficiently as possible. Network locates that there is an increase at the traffic of video service (traffic of elastic flows) that passes through the UMTS and decides to request from some devices to move to WLAN RAT. This decision is communicated to the user device; the latter are also able to continuously monitoring/interpreting context information and are able to select a system to connect in a personalized way. The terminal is able to monitor

different systems belonging to different operators. When the user was under UMTS coverage, he was experiencing a certain level of quality of service. However, after seamless handover to WLAN, service adaptation took place to exploit the better QoS levels provided by the WLAN network. In addition, the device may trigger protocol/software downloading and reconfiguration to adapt to the environment. The above procedures fall within self-configuration aspects of the device.

2. In addition, the case that the system predicts the traffic burst for this time period according to stored statistical data (i.e. a basketball match that takes place every Sunday), and reserves radio resources for different services is considered. As a result of this procedure, the base stations in this area are switched to a RAT with low coverage but high throughput, such as 802.11n. In addition, the increased number of users in a specific area may cause a BS to be incautiously broken by people. The system starts the self-healing process immediately. According to the user and equipment profile information, the system sends network and resource information to the users previously connected to the broken BS through the common Cognitive Pilot Channel (CPC) that help users to access other APs or BSs [13]. Parts of handsets are forced to reconfigure to a designated RAT according to their capabilities and the seamless requirements of services they were consuming. After this emergency service is successfully handled, a large number of users start attaching to this new 802.11n network, which results in overall quality of service degradation. When the QoS level falls below a defined threshold, the system automatically starts to negotiate with regulatory entities and other networks for additional spectrum band for 802.11n. In addition, in order to further assure a high level of QoS, another alternative solution can be considered: multi-homing and simultaneous-link capable devices may choose to operate multiple communication links in parallel. These links are maintained subject to generic policies (i.e., resource selection constraints) imposed by the network.

The main technical issues that are tackled in this scenario description are the following: context interpretation, RAT discovery and selection, seamless inter-system handover, autonomic decision making, software downloading, protocol self-configuration, traffic load prediction and balance, radio resource management, self-healing, dynamic spectrum allocation, flexible spectrum management, self-optimisation, multi-homing and policy derivation and provision. Note that IEEE P1900.B will define specific enablers (in particular protocols) which intend to support the smooth operation of a system in such a context. It is not intended to impose any operational parameters in the corresponding proposals.

III. The IEEE P1900.B System Concept

In order to assure an efficient operation of a large distributed wireless system, the presence of several, typically heterogeneous, Radio Access technologies (RATs) within the range of a Mobile Terminal (MT) is considered as illustrated in Fig. 1. Each heterogeneous cell is assumed to be either controlled by a single operator or a meta-operator regrouping several operators. Alternatively, it may be envisaged that a third-party service-provider is analyzing the QoS provided by distinct RATs and resource usage constraints are communicated to subscribers of the third-party service-provider independent from the network operators.

Contrary to single-link based legacy systems, this system concepts inherently assumes the presence to multiple reconfigurable radio front-ends in the MTs such that the devices may choose a link to distinct RATs simultaneously. This feature has several advantages, among others the following ones: i) the QoS per user is increased in terms of data-rate, link availability, etc., ii) the user may off-load independent data-streams onto distinct RATs in order to obtain the lowest communication costs for a required QoS level (e.g. low-latency, low-throughput link for VoIP applications, high data-rate, medium-latency link for video-streaming), etc. This concepts may be interpreted as a path towards the 4G inherent requirements on improved availability, higher data rates and other QoS measures.

It should be pointed out that the system concept proposed in Figure 1 targets to maintain the compatibility to legacy systems – the idea is to propose suitable evolutions to existing and evolving standards if required and to ensure a controlled cohabitation by introducing the following building blocks:

1. The Network Reconfiguration Management (NRM) entity provides context information (e.g., which RATs are available, which QoS can be ontained, etc.) and radio resource usage constraints, e.g. as illustrated in [8].
2. The Radio Enable of Reconfiguration Management (RERM) entity is the link between the NRM and TRM and may either be a physically dedicated channel or a logical channel. The corresponding information exchange may be bi-directional.
3. The Terminal Reconfiguration Management (TRM) takes context information & policies from NRM into account in order to decide on optimum radio resource usage strategies.

Note that the standard is expected to standardize enabler related information exchange mechanisms and protocols only. Resource selection and policy derivation algorithms and other functional choices are implementation dependent.
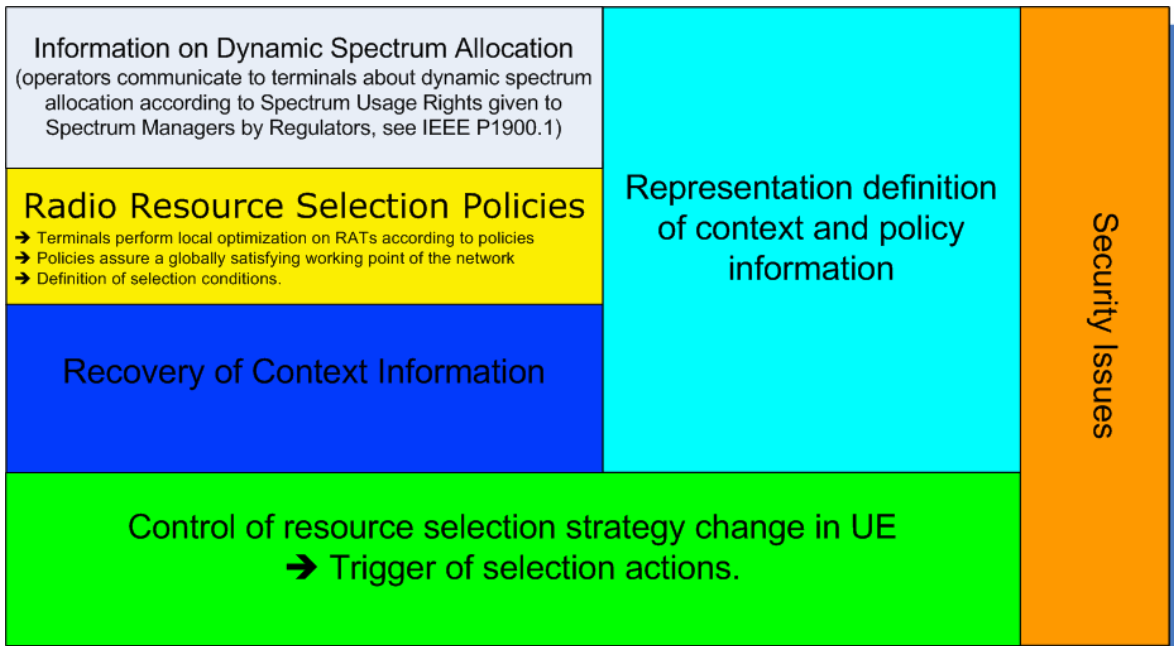
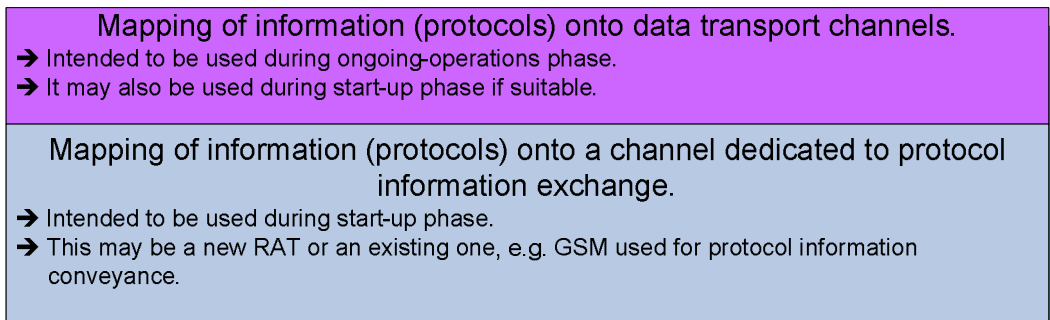**Figure 2: The Network Reconfiguration Management Unit.**

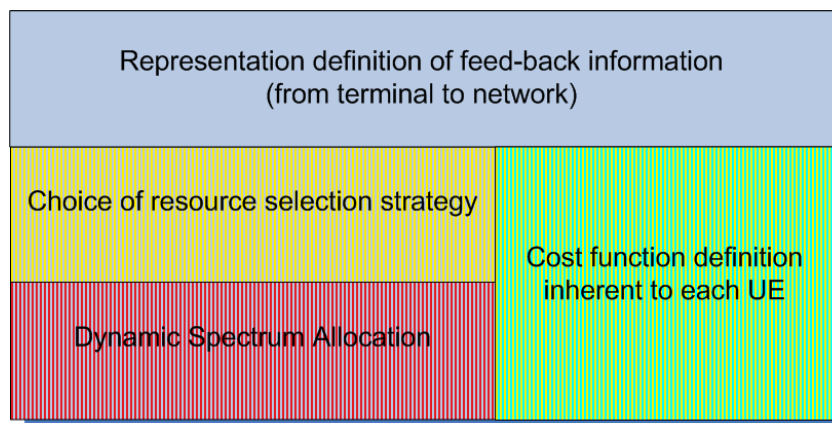**Figure 3: Radio Enabler Unit.**

Figure 4: Terminal Reconfiguration Management Unit.

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A proposal of the NRM, RERM and TRM architecture is illustrated by Figure 2, Figure 3 and Figure 4 – with detailed comments presented in the subsequent section. Beyond the introduction of the architectural approach and the upperly mentioned three building blocks (NRM, RERM, TRM), IEEE P1900.B is meant to be limited to the introduction of suitable management protocols in order to communicate context information and radio resource usage constraints from the network to the MT devices as well as to assure a feed-back link from the MTs to the network. IEEE P1900.B will thus not impose specific functionalities onto the network (meta-)operator, but rather provide enabling protocols which will be used by (meta-)operators in order to introduce resource selection constraints for the user equipment, to deliver context information and to provide corresponding means for an optional feed-back link from the uer equipment to the network reconfiguration management entity. This feed-back information is expected to be exploited by the network in order to refine policy and context information which is broadcasted to the user equipment.

IV. NETWORK RECONFIGURATION MANAGEMENT

On the network side, an operator or meta-operator uses the NRM entity in order to provide context information on the available resources, expected QoS, etc. to the users as well as information on radio resource selection constraints which need to be taken into account for the resource selection optimization performed in each terminal independently, i.e. based on distributed decision-making principles (related to the autonomic communications studies presented in [9]). The expected key functionalities of the NRM are illustrated in Figure 2 as commented in the following:

- The "Information on Dynamic Spectrum Allocation Rules" module is providing management protocols giving indications on Dynamic Spectrum Allocation rules from the network to the user device. The network (meta-)operator is meant to be able to define the level of distributed decision-making which should be granted to the user devices.
- The "Radio Resource Selection Policies" module gathers information provision functionalities related to resource selection optimization constraints to be imposed to user devices. The derivation of suitable policies (to be interpreted as Radio Resource Selection Constraints) is out of the scope of the standard and is assumed to be implementation and vendor specific. The network (meta-)operator is meant to control the level of decisions , which may be taken in the user equipment in a distributed way, by imposing suitable policies.
- The "Recovery of Context Information" module represents the interfacing of the NRM with the network equipment for recovery of operational information from the RATs as well as the optional link to user equipment providing feed-back on observed QoS, etc.

- The "Representation Definition of Context and Policy Information" module is presenting the effort on context and policy related ontology and management protocol definitions.
- The "Security Issues" module is expected to provide suitable security means in order to assure the ownership of the policies and context information provided by the network.
- The "Control of Resource Selection Strategy Change Change in User Equipment" module is expected to trigger the resource selection strategies within the user devices such that the distributed optimization is performed in a controlled manner. In particular, it is proposed to define a time-window during which specific user devices are able to update their respective resource usage strategies.

Beyond these blocks (meant to be defined in the standard), it is expected that a related implementation will comprise at least the following additional module:

- A "Detection of Policy Efficiency" module is expected to be introduced in order to derive metrics on the actual efficiency of policies which have been imposed by the network. While the policies are typically derived based on theoretical models, this block enable an adjustment of these models to the "real world" behaviour of the system.

The goal of communicating radio resource selection constraints to the MTs is twofold:

1. The constraints are meant to force the system in an optimum working point, i.e. the network capacity usage is optimum if all users optimize their radio resource usage strategies subject to the constraints imposed by the network. Obviously, the key task lies in finding suitable policies being compliant with this requirement.
2. Communicating global radio resource usage constraints to be considered for distributed decision making has advantages over a centralized parameterization approach in terms of signalling overhead and reactivity of the MTs. Optimally, a single policy is applied to all users; in practice, however, it is assumed that several user classes are introduced with a different set of network constraints imposed to each class independently. In the extreme case, one group may represent a single user and thus the network keeps the possibility to reconfigure each terminal independently if this should be required in a specific context. Typically, one group may comprise professional users while another one is related to private users only. In general, it is assumed that operators may choose to parameterize MTs independently in case that a small number of RATs and MTs are present within

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a heterogeneous cell; as soon as the number of indendent RATs as well as the number of users with reconfigurable, multi-front-end MTs rises, the optimization of resource usage is expected to be off-load to distributed decision-making approach with the inherent advantages presented above.

Please note that the network might typically try to identify radio resource selection constraints which force the MTs to converge towards a working point that is optimum from a global system capacity exploitation point of view. In a large heterogeneous scenario, however, this ambitious goal may be difficult to achieve due to the inherent optimization complexity issues. In this case, the intended goal can be shifted towards assuring the convergence into a working point that does not comprise any of very sub-optimum ones. In other words, it is then possible to force the system in a good, but not necessarily optimum working point while being sure that the really sub-optimum ones are avoided.

The key challenge within IEEE P1900.B consists in defining suitable protocols relevant to the communication of the above-mentioned context and resource selection-constraints information. The intention of the forthcoming Study Group meeting will thus be to introduce suitable protocols from the network to the terminal side in order to carry the relevant information. The physical realization aspects of the problem (implementation, discussion about dedicated physical channel and/or logical channel based on existing RATs, etc.) are out of scope of IEEE P1900.B.

In addition to these features, an optional feed-back channel from the MT to the network side will be introduced; this channel enables the user MTs to communicate information on QoS observations to the network equipment and the network may take these information into account for the optimization of the radio resource usage constraints related efficiency.

V. Radio Enabler of Reconfiguration Management

While the NRM entity gathers context information and control resource selection constraints, the RERM entity is responsible for the link between the network and the MT devices. The basic functionalities of this block are proposed as follows:

- The "Mapping of Information (protocols) onto data transport channels" module is representing the functionalities which are necessary in order to map context, policy and reconfiguration information onto existing RATs. In this process, the coexistence of useful user data and the cognitive information needs to be assured.
- The "Mapping of information (protocols) onto a channel dedicated to protocol information exchange" module is concerned with the usage of a dedicated

(potentially newly defined) physical pilot channel for provision of context, policy and reconfiguration information. It is expected that this channel is optional and will rather be used during a start-up phase. The reason lies in the fact that the inherent channel is assumed to be of low bandwidth and limited inherent data-rate and may thus be used for transmission of limited cognitive information only, typically for enabling an initial link to a user operating a device in an unknown environment.

This link may be maintained by a dedicated physical channel, a logical link via a already deployed Radio Access Technologies or a combination of both. There are indeed several inherent advantages of these solutions:

1. A dedicated physical RERM channel would enable devices a straightforward start-up procedure: they would recover the context information provided by the RERM and consequently know the available RATs. Subsequently, they are able to decide on their RAT selection strategy (subject to the radio resource selection constraints imposed by the network) and to connect to the relevant RATs without any band-scanning procedure. Moreover, basic reconfiguration data may be transmitted by the physical dedicated channel which would allow a MT to recover all information necessary to connect to RATs that are not supported by the MT profile at the time prior to the start-up procedure.
2. While a dedicated physical RERM implementation is expected to typically provide low data-rate services, complex reconfiguration information is expected to be delivered via a logical channel exploiting already deployed broad-band services.
3. A combination of the upper two solutions is expected to be the preferred approach, since the dedicated physical channel may mainly serve during the start-up phase while the logical channel is able to be accessed if large amounts of data need to be transferred to MTs.

Optionally, the RERM maintains a feed-back channel from the MT devices to the network, enabling a communication of user observations to the network, e.g. related to experienced QoS, etc. The network then may incorporate this information into the broadcast context information and/or the radio resource selection constraints communicated to MTs.

In general, the RERM entity is expected to operate in a broadcast-mode; however, it can also be envisaged that the users are split into sub-groups and different sets of context information and resource selection constraints are targeting distinct sub-groups; e.g. different types of subscription contracts may be envisaged with various cost/QoS trade-offs. Operators can also choose to restrict the size of sub-groups to a very small number of users (up to one single user) in order to

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be able to reconfigure a specific user by suitably constraint resource selection strategies targeting a single-user sub-group.

VI. TERMINAL RECONFIGURATION MANAGEMENT

The TRM entities are the distributed decision making cores located in the MTs. Their task is to perform decisions on suitable radio resource selection strategies, possibly maintaining links to distinct RATs simultaneously, subject to radio resource selection constraints imposed by the network. The context information provided by the network serves as knowledge to be considered for the optimization of radio resource selection. The proposed basic building block of the TRM are proposed to be as follows:

- The "Representation definition of feed-back information (from terminal to network)" module gathers terminal related parameters, such as obtained QoS, etc., to be communicated to the NRM via a feed-back channel. The goal is to provide terminal oriented information back to the network in order to support the context analysis and policy derivation mechanisms.

Beyond this block (meant to be defined in the standard), it is expected that a related implementation will comprise at least the following additional module:

- The "Choice of Resource Selection Strategy" module is performing the distributed optimization of the radio resource selection strategies inherent to all user devices subject to the policies imposed by the network. This operation is expected to rely on context information which is provided by the network via the RERM. It is important to note that each mobile device may perform this optimization with respect to its own cost functions (which are not necessarily known to the network) and parameters (in particular, reconfiguration parameters). This approach will thus enable the device to perform the optimum choice of the resource usage strategy which is guaranteeing a high system capacity (thanks to network policies) and which is exploiting the capabilities of the user device itself.

- The "Dynamic Spectrum Allocation" module is performing similar tasks compared to the "Choice of Resource Selection Strategy" – however, it is related here to dynamic spectrum allocation tasks only. It is moreover expected that the network operator will only grant very restricted distributed spectrum allocation optimization, while the optimization of the usage of RATs may be distributed in a broader way.
- The "Cost Function Definition inherent to each UE" module is meant to introduce a controlled trigger of the reconfiguration in the mobile device. The goal is to avoid that a large number of users is adapting the respective resource selection strategies in a completely uncontrolled fashion. In particular, game theoretic inspired resource optimization schemes typically rely on a controlled adaptation of the selection strategies of the different users.

Optionally, the user MTs can communicate observation, such as experienced QoS, interference levels, etc. back to the network. These can then be taken into account by the network in order to refine the context information and/or radio resource selection constraints which are broadcast to all user devices.

Typically, each user device is targeting an optimized radio resource usage from its "personal perspective" - regardless of the global network efficiency (which generally is unknown to the device). Ideally, the radio resource selection constraints imposed by the network, however, will force the choices of the MTs to assure a optimum or quasi-optimum working point not only for its personal perspective, but also from the global network's perspective. An example of such suitable constraints is discussed in [8].

VII. A CASE STUDY ILLUSTRATING THE IEEE P1900.B SYSTEM CONCEPT

At this point it should be noted that the functionality that is required for Network and Terminal Reconfiguration Management is supported by the Selfware-Reconfiguration Management and Control Plane (S-RMP) [10]. Such plane offers coordinated management and control functions that support the procedures that are necessary for the reconfiguration initiation, coordination and final implementation in a dynamic fashion. The S-RMP spans across both Network and Terminal Reconfiguration. This plane is used in the standardization process by first presenting inherent functionalities on a global (plane) level represented by the S-RMP. In a second step, the inherent functionalities are mapped onto the NRM, RERM and TRM blocks. This approach is expected to guarantee a coherent definition of all functionalities across the full system.

Targeted to illustrate the basic concepts of the IEEE P1900.B building blocks, the first phase of the scenario described in Section II is analyzed. This scenario involves the main S-RMP modules, the Autonomic Decision-Making and Reconfiguration Management (ADM-RM) module, the Cognitive Service Provision (CSP) module, the Software Download Management (SDM) module, the Self-Configuration and -Management (SC-M) and the Context Management (CtxM) module. The functionality of these modules is further described in [10].

A. Signaling

This section analyses the signaling required for the implementation of the first step of the scenario that was described in section II, based on the System Architecture supporting the IEEE P1900.B concept (Figure 5).

The network side CtxM detects an increase at the elastic traffic service (e.g video streaming service) at a specific area

and sends a resource optimization report to the ADM-RM module. Thereinafter, the ADM-RM takes into consideration the different policy rules (i.e. rules defined by the mobile network, the manufacturer or the user) and the resource optimization reports so as to specify a reconfiguration decision targeting the optimum resources utilization. This decision concerns multimode mobile devices, which consume video services, to switch RAT and hook to WLAN (from the existing UMTS RAT).

Thereafter, ADM-RM retrieves from the profile repository (CTxM) contextual information (terminal and user profile), in order to define the group of mobile devices that can support the network initiated handover, based on their capabilities. In the sequence, NRM through the Radio Enabler mechanism requests from the mobile devices that have been identified to gradually switch to WLAN.

The Terminal Reconfiguration Management mechanism undertakes to control the process of RAT switching. Taking into account the defined policy rules (users and application requirements, resource availability and business objectives),

TRM and specifically ADM-RM, approves and initiates the reconfiguration process. However, it discovers that in order to proceed with the RAT switching and adapt the video service, it is firstly required to update the corresponding mobile device software application. ADM-RM informs CSP module, which issues a "reconfiguration service discovery" request to the respective network CSP module, asking for information about application's reconfiguration. The network CSP processes the request and provides information about the reconfiguration of the video application. In particular, it is required to download a software component (e.g. codec), which will provide the missing functionality. The terminal CSP module informs ADM-RM about the response, which next triggers terminal-initiated software download by negotiating with SDM module. The latter coordinates with the corresponding network SDM module for the realization of the software download. After the completion of the download phase ADM-RM triggers SCM to undertake the enforcement of the respective application reconfiguration, by replacing the old component with the new one [12]; the latter procedure will enable service adaptation and will finally lead to the RAT switching.
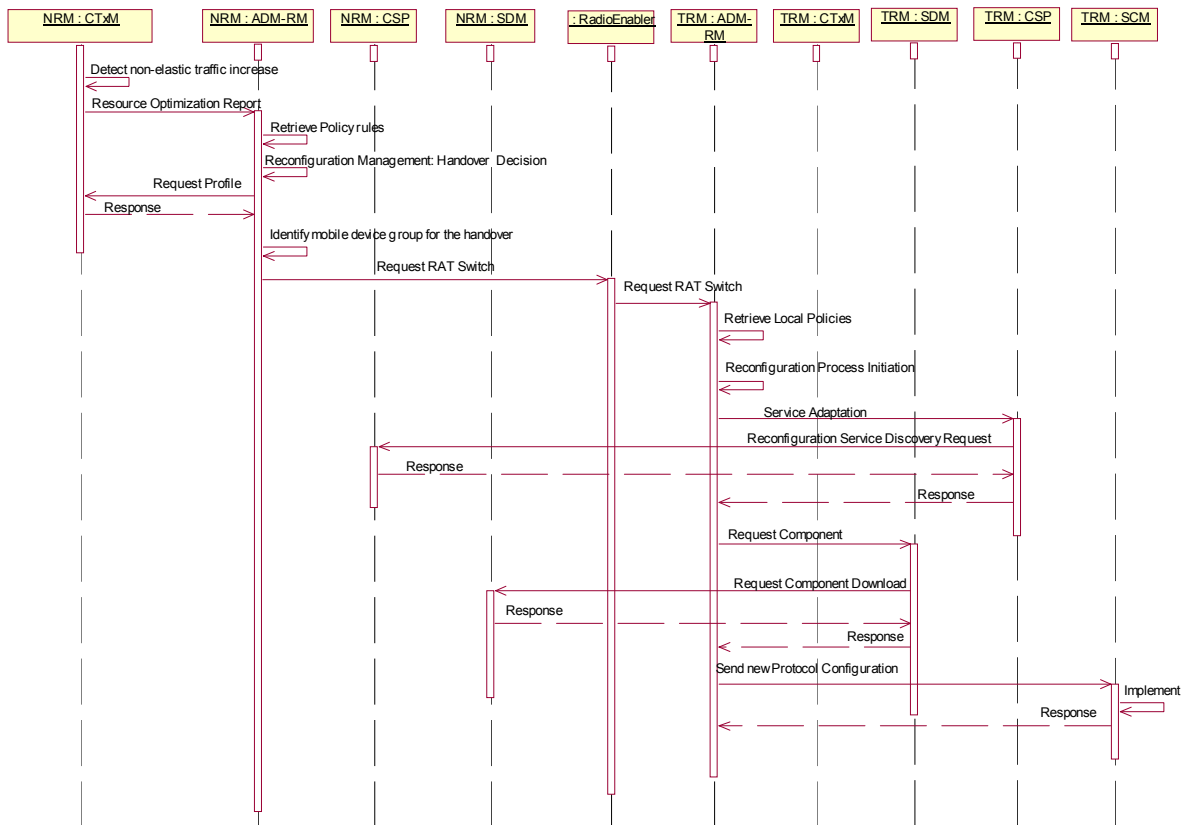

Figure 5: A scenario illustrating the IEEE P1900.B System Concept

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VIII. CONCLUSION

This paper has provided an overview of the current status of the IEEE P1900.B standardization effort related to *Coexistence Support for Reconfigurable, Heterogeneous Air Interfaces* [1] and indications on the further progress in the follow-up IEEE P1900.4 WG; inherent concepts are discussed and typical applications presented. It is illustrated that the distributed decision making approach followed by the IEEE P1900.B group has a number of advantages:

1. A minimum signaling overhead is achieved since (ideally) radio resource selection constraints are derived for all users in the network and are efficiently broadcasted to all entities. In practice, however, a less efficient multi-cast mode may be chosen in order to communicate distinct constraint sets to sub-groups of user devices.
2. Contrary to a centralized parameterization approach of the user devices, the distributed decision making concepts allow a high reactivity of the user devices since they choose themselves at which pace the resource usage strategy is updated.

It should finally be pointed out that the B3G system concept targeted by IEEE P1900.B is bringing control into a quasi-existing heterogeneous environment. As a matter of fact, user device have today the possibility to "autonomously" connect to distinct RATs without any control from the network side. This anarchic joint-resource usage, however, proves to be inefficient from a global network capacity usage efficiency perspective – in particular if the heterogeneity of the considered scenario still increases. At this point, control mechanisms as the one presented in this paper need to be introduced.

Finally, future steps include the specification of example use-cases and the derivation of respective capabilities based on the basic building blocks of the distributed architecture. Such capabilities will be used for the identification of suitable functional operations in the functional architecture that will be proposed by the IEEE P1900.B group.

ACKNOWLEDGMENTS

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