Compelling Needs and Technologies to support Reconfigurable Terminals

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Abstract: *To date, research into reconfigurable mobile communications has predominantly focussed on the software radio concept, and specifically on the hardware technologies required to move physical layer processing into a programmable environment [1][2][3]. Although an interesting and necessary challenge, this only represents a fraction of the overall support and technology required to realise the potential of the concept. Other necessary developments include network/terminal cooperation for seamless inter-standard handoff, QoS management, a secure software download mechanism, terminal software architecture supporting reconfiguration, configuration management, capability negotiation, etc.. Summarising results from early IST-TRUST (Transparently Reconfigurable UbiquitouS terminal) [4] project deliverables, this paper describes the likely overall system environment and the key technical challenges to be researched in TRUST for realising a reconfigurable terminal to meet the needs of users within that environment.*

Future wireless systems

As we move towards the 4th Generation of Mobile Communications, we can perceive the convergence towards an IP-based core network and ubiquitous, seamless access between 2G, 3G, broadband and broadcast wireless access schemes, augmented by self-organising network schemes and short-range connectivity between intelligent communicating appliances (Figure 1) [5]. In general, vertical handover takes place between different access systems (cellular layer down to personal network layer, e.g. Bluetooth). Vertical handover is combined with service negotiations to ensure seamless service, because different access systems support different user data rates and other bearer and service parameters. The interworking, mobility management and roaming will be handled via the medium access systems and the IP based core network. Reconfigurable radio terminals and new appliances are key components of such a seamless network.

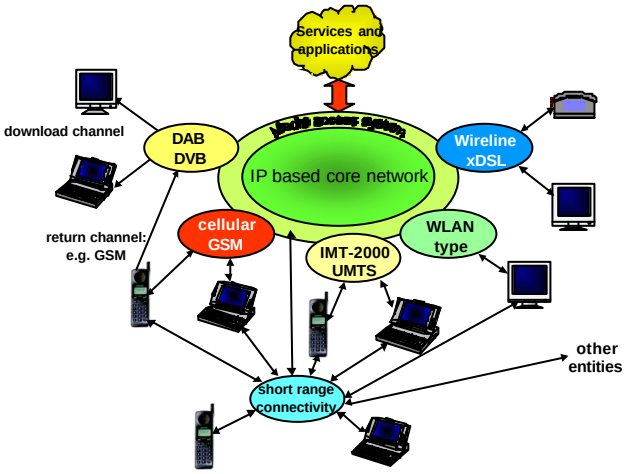

Figure 1: Seamless future network including a variety of access technologies [5]

What does all of this mean to the end-user? Potentially, the value would be in the diversity of mobile applications, hidden from the complexity of the underlying communications schemes. This complexity would be abstracted into an intelligent personality management mechanism, learning and understanding the needs of the user, and controlling the behaviour of their reconfigurable terminal accordingly in terms of application behaviour and access to the supporting services.
TRUST attempts to rationalise this 'seamless wireless utopia' by studying the 'real' requirements for reconfigurable terminals and creating realistic working scenarios. Technology research will identify the system support concepts, enabling technologies and standardisation required to realise the scenarios, and through subjective evaluation, system modeling and simulation, will evaluate the feasibility of the proposed solutions.

Requirements and Regulatory Issues

Requirements for Future Mobile Communications from the User Perspective

As can be seen, reconfigurability touches the PCS network in many places. Each of the potential 'features' interact in a way that affects all users. Rather than presenting a technology utopia, TRUST's user requirements approach [9] focuses on the study of 'real' early adopter users and operators. Throughout the project these user groups will be used to generate real usage scenarios and requirements.

Derived from early TRUST qualitative work, Table 1 shows the dominant high level requirements for reconfigurable radio from the perspectives of users, application/content providers, service providers, network operators and equipment manufacturers. Based on these requirements, the demands on the system concept and enabling technologies may be derived.

END USER HIGH LEVEL REQUIREMENTS	
Ubiquitous mobile access	Robust connection is essential Access to mobile-specific web, multimedia, broadband and broadcast content: seamless handoff between radio access modes (user not interested in which ones). Service discovery and transparent dynamic adaptation of applications to match available services and preference profiles; Home country roaming will become an issue for users Global roaming (important for only a small subset of potential users)
Quality expectations vary with task	Service degradation and dropped service (eg broadcast TV, interactive games, voice telephony) must be managed. Similar levels of service are expected on the train as in the home. User must have high-level control where cost is concerned.
Ease of access to applications and services	Current technologies will set benchmarks (eg Internet download) Transparent discovery and switching between services and radio access modes, based on an intelligent establishment and interpretation of user preferences and application requirements. However, some users will require more control for private vs. business use.
Low cost and relevant services and meaningful billing	Intelligent discovery, presentation and selection of service options and billing schemes; distribution of application processing between network and terminal to reduce terminal resource requirement. Billing should hide some of the inherent system complexity, i.e. only one bill. Set cost constraints for services
Technology comfort	User friendly consumer product model versus computer (PC) model: computer-literacy should not be required but may be useful. Intelligent client-server management schemes and middleware must offer the user freedom from complex PC-like application installation and system configuration/maintenance; but users may still want some control; User-friendly handling of delays, disconnections and new connections via meaningful feedback to the user; Transparent handling of version/configuration control for application and system software (including radio access stack software). Accountability of system to user for reconfiguration changes. Support expected from the service provider and operator in finding services and updating software. Intelligent use of battery resource, both locally (local application, display, sound) and in network access Simple UI and appealing aesthetic.
Reasonable equipment life	Expectation that terminal equipment will offer support for fast-evolving complexity and diversity of applications and services
APPLICATION DEVELOPER/CONTENT PROVIDER	
Common Execution Environment	Allowing development of applications and associated content independently of underlying network services and terminal capabilities: self-configuration via capability exchange
Application Diversity	Terminals capable of supporting fast-evolving complexity and diversity of applications and services; Utilisation of increasing terminal resources to enrich application (eg spare DSP processing capacity)
SERVICE PROVIDER	
Fast, open service creation,	Allowing development of services independently of underlying network services;

validation and provisioning	Provisioning of validated services configured to underlying network and terminal capabilities
Inform user of services available	Requirement for an effective scheme to 'advertise' available services in a service discovery negotiation
Maintain connections and adapt to required QoS	Ability to seamlessly switch connections to alternate radio access schemes or alternate network operators both in call and in standby Dynamically modify resource allocation to maintain desired QoS over radio channels
NETWORK OPERATOR	
Maximise utilisation of allocated spectrum	Flexible allocation of spectrum according to differing user demands. Radio resource and network management to support coexistence of access schemes within allocated bands and spectrum sharing between operators.
Maintaining QoS	Maintenance of Quality of Service is a fundamental measure of network operator performance
Longevity and flexibility of network equipment	Supporting reconfiguration in the radio access equipment and the media access fabric interfacing to the core network
Owning customers	Mechanisms to support operator control of terminals, at all levels
TERMINAL AND COMPONENT MANUFACTURER	
Economies of scale	Consolidation of product variants onto reconfigurable product platforms
Bug fix and software enhancement provisioning	Ability to download and install software to overcome bugs and enhance functionality/performance reduces recall costs and increases differentiation and revenue stream
Fast product creation	Reconfigurable IP authoring fostering maximised reuse, hardware/software codesign and platform-based IP integration methodology

Table 1: Reconfigurable Mobile Communications Requirements Study

Regulatory Considerations

Reconfigurable radio technology is acknowledged by FCC, the US regulatory authority, as an important mechanism to allow the modernisation of spectrum engineering practices to improve spectrum efficiency [6]:

- Efficient use of available spectrum: Implies new spectrum engineering practices to allow coexistence of radio access schemes within operators' allocated spectrum, and to permit dynamic allocation and sharing of spectrum between operators;
- Manufacturer self-approval of equipment conformance: Manufacturer is liable for conformance of the terminal to network/inter-operator planning, radio resource management and network integrity rules.
- Effective method of approval for radio-specific programmable terminals: Coexistence and regular updating of radio, system and application software in a terminal, potentially utilising shared terminal resources. Requires a radically different type-approval process and a robust resource management/negotiation/protection scheme.

Mapping requirements to technologies

Analysis of the needs and regulatory issues 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

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

A key enabler for reconfigurable radio systems, 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. A common terminal execution

environment for *applications*, supporting WAP and personal-JAVA is under development by the MExE (Mobile Execution Environment) standard [7].
TRUST will investigate extensions to MExE 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

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 realise the user-friendly, ubiquitous environment demanded by the 4G 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 creation/update and secure management of user preferences
- Intelligent service discovery and presentation
- Intelligent configuration of applications to terminal and service capabilities and user preferences
- Secure software download
- Distributed processing for applications
- Distributed 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 realised.

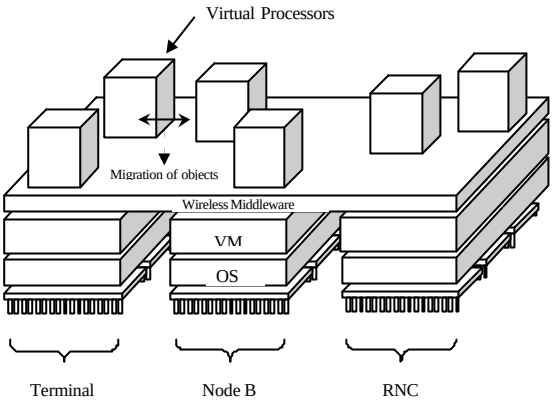

Figure 2: Virtual Backplane in a Distributed Processing Environment [5]

Radio Reconfiguration Control

These functions represent the key enablers for reconfigurable terminals to provide the connectivity, mobility, reliability, security and QoS required to access the potential of the evolved 4G network scenario and thus to deliver the user requirements. Some terminal-centric solutions exist today and represent the state-of-the-art [8], however maximum benefit requires terminal/network cooperation and this is a central theme of TRUST system aspects research. Novel solutions will be proposed and evaluated in terms of complexity, performance, overhead, tradeoff 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, capability exchange and integrity assurance
- Efficient algorithms to realise flexible, robust radio access schemes
- Flexible, reconfigurable terminal/basestation software and hardware architectures

Constraining Considerations

The concept of reconfigurable mobile communications by its very nature implies ever increasing flexibility, resulting in a potential system management nightmare. TRUST will 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
- Transparent introduction of software may hide or disable functions provided by a competitors application (anti-trust);
- Use of intelligent user preference establishment and maintenance schemes to customise 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). Whilst not specifically developing framework/middleware solutions [1], TRUST will identify the framework functionality needed to support the key reconfigurable terminal system technologies, estimate key tradeoffs and examine feasibility.

TRUST – Technical Approach

TRUST examines the requirements for reconfigurable terminals, primarily from an end users perspective of a reconfigurable system. Results will define both system support functions and underlying enabling technologies required to realise the benefits. These technologies will be researched, utilising system modeling and simulation to assess the complexity, performance and feasibility of identified novel solutions. Wider system implications will be addressed by a system focus team, identifying requirements for clustering and further research beyond the scope of TRUST. Results will be disseminated through an international workshop on Reconfigurable Mobile Communication Systems organised by the project, and through presentations and contributions to appropriate standards organisations, spectrum regulators and conferences. This will create awareness in the mobile communications community, of the needs and challenges for deployment of user friendly reconfigurable terminals offering ubiquitous service over multiple radio access technologies.

User Assessment

A systematic study of user activities and cost-benefit relationships, via focus group discussions, operator interviews and simulated application demonstrations will define a set of compelling user scenarios which will drive the technology research [9]. This will be augmented by a wider study of regulatory issues and constraining factors.

System Support Research

Following a detailed state-of-the-art study, research will be focussed on:

- Yielding novel ideas and developing techniques to maximise efficient and effective use of the radio spectrum resources in the context of software defined radio, via investigation into advanced spectrum allocation and sharing techniques in the context of an evolution of spectrum engineering practices
- Software download: examining network-terminal cooperative solutions to the security, regulatory, configuration, capability and resource management considerations regarding download of radio-specific, service-specific and application software or parameters. Consideration of the need to evolve the type approval process to handle radio reconfiguration, and extensions to standards to provide a framework to realise the potential benefits (eg extensions to MExE to allow download of radio software components and parameters below the application layer). Various schemes will be evaluated, including point-to point, multicast and background download. Protocols proposed to the SDR Forum by ACTS FIRST will be further developed, including radio resource quantification, authentication techniques, capability exchange and configuration management.

- Radio access mode identification, monitoring and switching: Determining the existence and availability of alternative radio access modes by pilot, assisted or blind methods. Examining the criteria, QoS measurements and algorithms involved in and making a decision to switch radio access modes, and the support and signalling required to execute the switch. Understanding the network/terminal cooperation, middleware and protocols required to realise 'soft' inter-mode handoff, using switching between 3G modes and HIPERLAN2 as a test case.
- A system focus effort will examine the need for system frameworks and middleware to support technologies developed by TRUST.

Enabling Technologies and Algorithmic Research

Research into underlying terminal technologies will focus on:

- Analogue signal processing transceiver architectures: examining system requirements and constraints, proposing and evaluating performance of architectural and derived component solutions. Issues include linearity and efficiency demands on power amplifiers, evaluation of tuneable channel pre-selection filtering schemes, signal cancellation, digital conversion, linearity enhancements and digital control techniques. An assessment of analogue signal processing impact based on the need for simultaneous service connections will be undertaken.
- Proposal, evaluation and performance analysis of a digital signal processing architecture supporting a reconfigurable object-oriented analysis of the physical layer processing. Reconfiguration by parameter download and incremental download of classes to support the modified access mode will be examined. Architectural support entities will be proposed (eg. class library, reconfiguration management and terminal management entities).
- Development of algorithms applicable to flexible transceiver architectures, augmenting spectrum sharing research: analysis of a slow frequency hopping multicarrier DS-CDMA scheme including synchronisation aspects and multi-user detection analysis, SINR-based adaptive rate transmission schemes, space-time coding + beamforming/antenna array algorithms in conjunction with Turbo equalisation. Such a scheme has compatibility with 2G, 3G, BRAN and unlicensed schemes, allowing users to exploit the whole system bandwidth and to efficiently utilise frequency resources.
- A reconfigurable hardware validator will be developed to demonstrate the effect of scalable video applied over an adaptive modulation scheme in a UTRA-FDD radio access mode.
- Power management will be investigated at both system and component levels. System issues relate to QoS and mode establishment using power budget and remaining power as criteria.
- Scalable video coding: performance of the H.263+ scalable video coding scheme under dynamic channel bandwidth variations, and object-based scalability in MPEG4 will be assessed. Wavelet filter techniques for scalable image coding will be explored and evaluated against metrics defined in the user requirements analysis.

Dissemination and Standards

Creating an awareness of the potential benefits and challenges for reconfigurable radio systems from both an end user and a technology perspective will be achieved through dissemination via:

- An established TRUST public website [4];
- An international workshop (16-10-00, Kings College, London) providing presentations and panel discussions from technical, regulatory and human-factors specialists to consolidate a common vision, user needs and research directions for 'reconfiguration';
- Presentation of white papers (user needs, technology research) to global standards organisations (eg 3GPP, ITU) in preparation for fourth generation standards development activities.
- Proactive participation in IST clustering to share research results and identify new/missing research areas. TRUST co-ordinates the umbrella cluster on Reconfigurability (Vision on Reconfiguration in Mobile Radio Systems), to include Service Provider and User Requirements, System Concepts and Enabling Technologies subclusters [10].

Regulatory questions raised by FCC will be augmented with European perspectives, and the project will respond based on technical research undertaken. Needs for modification of the standardisation process to support reconfiguration will be assessed and specific standards contributions will be made as appropriate. These are likely to recommend extensions to developing 3GPP standards such as MExE and VHE (Virtual Home Environment) to support reconfiguration and radio-specific software download concepts.

Conclusions

Given a heterogeneous mobile network environment, reconfigurable terminals have the potential to provide a user-friendly interface to rather complex network interfaces. Based on a realistic user assessment, the key system support functions and enabling technologies are being established by TRUST, taking account of anticipated regulatory and technology constraints and developments. Proposed solutions will be assessed for feasibility through modeling and simulation. Seamless service provision, scalable QoS, distributed applications and intelligent reconfiguration management may be managed by a distributed processing environment and configuration management scheme. TRUST will determine the user requirements, deliver validated concepts to address the key system-level functionality, identify the needs for a supporting system framework and produce roadmaps and architectural models for key enabling technologies. Based on available and future enabling technologies, TRUST system concepts will be designed for compatibility with both future and existing radio access standards (GSM, UMTS, HIPERLAN2, etc.).

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