WINNER - Towards Ubiquitous Wireless Access

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Abstract— **The huge growth in wireless communication has led to a wide range of technologies each addressing a particular scenario or need. The goal of the WINNER project is to develop a single new ubiquitous radio access system concept to address the whole spectrum of mobile communications scenarios. This paper surveys the challenge of providing ubiquitous operation and introduces the key technologies investigated in WINNER to meet these needs.**

Keywords-air interface, ubiquity, B3G

I. Introduction

The last decade has seen an explosion in wireless technology use with mobile phone penetration reaching saturation level in many countries and the rise of wireless LAN availability in offices, airports, hotels and homes. This has also been accompanied by increased performance in terms of data rates with, for example HSDPA providing up to 14Mb/s (theoretical) peak date rate and 802.11g 54Mb/s, accompanied by progressively lower delays. These performance improvements have enabled an increasingly rich range of services to both the consumer and business user – download of video clips and music tracks (for example through Vodafone Live!) and remote working by access to corporate e-mail and other systems.

Radio technologies continue to evolve both in the existing standards bodies – 3GPP is working on RAN Long-Term Evolution [1]and IEEE is working towards 100Mb/s WLAN in 802.11n – and with the development of many proprietary solutions (Flarion's Flash-OFDM and ArrayComm's i-Burst). However all these technologies are targeted to specific scenarios. The wireless research community is now looking to "Beyond 3G", where commonly quoted targets are the data rates set by ITU-R for research purposes of 100Mb/s aggregate data rate in wide area and 1Gb/s aggregate data rate for short range [2].

The WINNER project [3] was created to research towards a "B3G" air interface. It is an EU-funded consortium of 38 partners made of universities, manufacturers, operators and research institutions. The project is divided into 7 workpackages co-ordinated by the system engineering activity (WP7) and driven from work on scenarios (WP1). Key technical work is in 3 areas: radio interface (WP2), deployment concepts focused on relaying (WP3) and inter-working with legacy systems (WP4). Enabling activities on channel measurement and modelling (WP5) and spectrum (WP6) underpin the other activities.

The overall goal of WINNER is to develop a single new ubiquitous radio access system concept whose parameters can be adapted to a comprehensive range of mobile communication scenarios from short range to wide area. This will be based on a single radio access technology providing enhanced capabilities when compared to existing systems or their evolutions, in economically feasible manner.

The paper is laid out as follows: firstly the problem of ubiquity is defined with resulting requirements. Section III introduces the adaptive radio interface approach of WINNER with section IV outlining the key enabling technologies. Conclusions and further work are given in section V.

II. Problem Space of Ubiquity

The stated goal of WINNER is a "single new ubiquitous radio access system concept" but what does this really mean? Ubiquity touches many different aspects of a wireless system, a number of which are inter-linked. Some of these are discussed below and resulting requirements are presented.

A. Coverage

An underlying part of the success of cellular mobile systems is the ability to make contact (via voice call or SMS) from virtually any location. It is found to be extremely frustrating when a call can't be made due to poor coverage. In the future this same universality of service will need to be maintained and we need to understand for which services this is important.

On the other hand recent years have seen the rise of nomadic usage of wireless services through wireless LAN hotspots. And it could be argued that there is a linkage between services and the provided coverage – i.e. e-mail and business services are primarily used in offices, hotels and airports. However these patterns are beginning to break down so that users may not feel constrained to using business services in “work spaces” or consumer services in “leisure spaces”.

In addition to the coverage area the system must also be adaptable to the range of user densities from sparse to highly concentrated.

B. Radio environment

As is well known different environments lead to different radio conditions – a dense urban centre city presents a different challenge to a train line through the countryside to an indoor meeting room. Each radio environment that we encounter ideally requires an individual optimisation. This is obviously easier if the system usage is restricted, e.g. WLANs to indoor, GSM/3G for wide area but when seeking ubiquity this imposes the need for flexible parameterisation of the physical layer.

The speed of the end user is also a crucial parameter – from stationary users in a cafe to pedestrians and vehicular users to users on high speed trains. Importantly high performance services (in terms of data rate or delay) by the user is are not necessarily only required at low speed – the prime case being a business user on a train downloading files.

C. Spectrum

Spectrum is the basic resource that is necessary to deploy a wireless system. Traditionally spectrum has been linked with certain technologies and has been assigned to operators through beauty contests or auctions. The trend is now towards more flexible spectrum regimes with mobile bands becoming technology neutral and the possibility of spectrum trading. This means that operators will have opportunity to have a very diverse spectrum portfolio, which in turn requires a ubiquitous radio system to be able to operate across a wide range of frequencies and bandwidths. For WINNER this has led to the following requirements:

- Existing spectrum below 2.7GHz
- New spectrum potentially identified at WRC-07 between 2.7GHz and 6GHz
- Bandwidths from 2.5MHz to 100MHz

A further aspect of spectrum that should be considered is the type:

1. Dedicated for a single deployment of a system
2. Shared between multiple deployments of the same system
3. Shared between multiple deployments of different systems.

Cellular systems today are of the first type operating in licensed spectrum with WLANs falling into the third type in unlicensed spectrum. It is probable that if large bandwidths are required for “B3G” systems that they will need to operate in a shared manner in order that sufficient spectrum can be found.

D. Services

Services have already been touched upon in the coverage section – i.e. “where”, however the “what” is also a very significant area. We can expect in the future the range of services that users wish to use wirelessly to increase with capabilities necessary that are beyond today’s systems. A rigorous scenario process was carried out in WINNER [4], which identified 18 service classes. These cover the entire range of characteristics from low to high data rate, low to high delay, required BER and point-to-point and point-to-region in numerous combinations. WINNER should support all these service classes.

E. Business models and deployment types

There are currently a number of different players providing wireless services [4] – traditional cellular mobile telecommunications providers, virtual operators, wireless ISPs, commercial hotspot (WLAN) providers, “value add” hotspot operators (e.g. coffee shops) and free hotspots (community provision or members of the public). In the future other players are likely to enter this space in some form – broadcasters, entertainment firms etc. Each of these players operates on a different business model and typically different technologies support these. The ubiquitous system concept should allow the deployment of the system in different configurations to enable this variety of business models. Further to these fixed deployments there is likely to be a growing trend of direct communication between user terminals for sharing music files, ringtones etc. The WINNER system has a requirement to support this Peer-to-Peer (P2P) communication as well.

F. Users

Finally, but most importantly the user. As is well recognised today with the drive to market segmentation there is huge variety of users, who use different ranges of services in different ways.

III. ADAPTIVE RADIO INTERFACE

A. Introducing Modes

The discussion in the previous section has shown that in developing a ubiquitous system concept there is a large and diverse set of problems to be addressed resulting from the fact that the scope of WINNER is greater than that of any single communication system developed in the past. The amount of flexibility and adaptivity required is considered to be too large to be accommodated without some significant change in system parameters; otherwise the system performance may be compromised in some area. Therefore the concept of “modes” is introduced with the following key principles:

- A minimum set of modes should be defined in order to meet the WINNER requirements
- There will be the highest degree of commonality possible between the modes

- A mode will only be defined where the flexibility/adaptivity required by a driver (issues discussed in section II) leads to a fundamental difference in the technical solution, whether that is the physical, MAC or RRC layer.

There are a number of technology areas that make up a radio air interface, where choices could be made leading to different "modes" – duplex scheme, underlying modulation (e.g. OFDM or single carrier), multiple access, relaying (use or not), spatial processing, carrier frequency, bandwidth, MAC or RRC functionalities.

Having reviewed the drivers it has been identified that there are only 2 areas, where distinct choices need to be made:

1) Duplex scheme

In order to operate across a range of coverage types (e.g. full nationwide, "hotspot") as well exploiting the range of spectrum allocations available WINNER will support both half-duplex FDD and TDD. All other physical layer components will be the same, although some parameters may differ. We denote these Physical Layer Modes (PLMs)

2) MAC

Three different MACs are required in WINNER:

- FDD "cellular"
- TDD "cellular"
- P2P

The direct communication between two user devices clearly requires a different mechanism on the MAC layer. An area of further study is to determine if the FDD and TDD "cellular" MACs can be merged. Fundamentally the WINNER MAC assumes operation in shared spectrum; with dedicated spectrum defined as a subset of this general case.

B. Adaptive Parameters

Beyond these differentiators into different modes all other parameters can be considered adaptive, with the system selecting (either in real-time or in the implementation) the optimal choice dependent on the conditions existing.
Link adaptation takes place in the MAC and physical layers. The MAC primarily controls the FEC and the physical layer controls both the basic transmission parameters such as the code rate, modulation, OFDM parameters and the spatial processing algorithm (see below).

IV. KEY TECHNOLOGIES

This section briefly reviews the key technologies that support the adaptive radio interface.

A. Modulation

Frequency domain based (block) signal processing is a natural choice for future high bit rate wireless air interfaces as signal processing complexity per data symbol rises only logarithmically with the channel delay spread [5]. In this context, the Generalised Multi-Carrier (GMC) approach used within WINNER enables to accommodate different flavours of both serial modulation (e.g. single carrier, DS-CDMA and IFDMA) and parallel/multi-carrier modulation (e.g. OFDM(A), FMT and MC-CDMA) by appropriate use of FFT and iFFT operations at transmitter and receiver. Frequency domain processing enables transmission links to easily and adaptively shape their transmitted spectrum occupancy in response to user terminal requirements and the availability of unoccupied spectrum – thus facilitating the generation of *multi-band* signals [6]. It also enables flexible choice of bit rates, modulation formats and multiple access schemes, according to need.

OFDM and OFDMA can employ adaptive loading (allocation of data and power to subcarriers), to approach optimal use of bandwidth whereas serial modulation has a lower peak to average power ratio (PAPR) and requires less terminal power backoff than OFDM[6]. Using the GMC approach, a user terminal may thus easily switch from transmitting OFDM in a microcell indoor environment, to serial modulation in an outdoor environment, where terminal power amplifier efficiency and cost have paramount importance [7].

Figure 1 shows an overview of transmitter for the WINNER system. The structure is the same for all cases of GMC, only requiring appropriate configuration. For example, if using the transmitter for single carrier transmission generated in frequency domain, then the GMC block will be a FFT prior to any spatial processing.

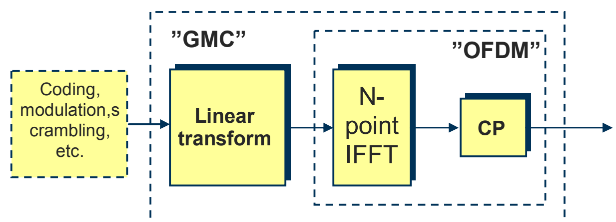

Figure 1. GMC transmitter

B. Spatial Processing

The WINNER multi-antenna concept [8]is a generic architecture that aims at performing *multi-user spatial domain link adaptation*, based on the following basic components:

- (Linear) dispersion codes,
- Directive transmission (beamforming),
- Per stream rate control, and
- Multi-user precoding.

This architecture allows fostering all spatial processing gains (i.e. spatial diversity, spatial multiplexing, SDMA, beamforming, and interference management by spatial processing) in flexible combinations as required by different scenarios.

A generic downlink transmitter is shown in Figure 2. SDMA allows reuse of the basic time-frequency units, called chunks, in form of spatial chunk layers. After these chunk layers have been allocated by the resource scheduler, adaptive modulation is applied. An optional non-linear precoding stage may be used in particular for high data rate demands in low-mobility scenarios using the TDD mode. Then the proper amount of spatial diversity and multiplexing is introduced by adaptive dispersion coding. Linear dispersion codes (LDC) represent a large number of so-called vector and matrix modulation schemes including (quasi) orthogonal space-time block codes, high-rate non-orthogonal codes, and BLAST-like transmission. If partial channel knowledge is available, per stream rate control provides an additional option.

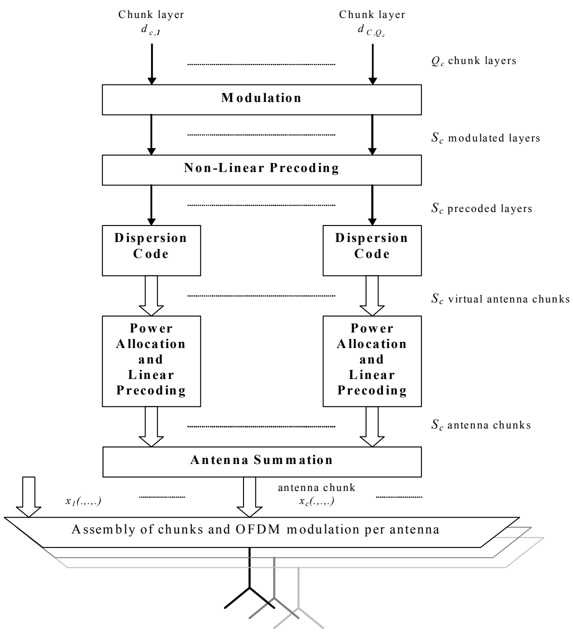

Figure 2. Generic Spatial Processing Block diagram

Finally linear precoding in its various flavours from fixed grid-of-beams, over single-user (eigen)-beamforming, to linear multi-user precoding can be applied. Beamforming provides an effective means to improve the link budget, increase coverage and control interference, especially in macrocellular environments. Linear multi-user precoding provides an additional increase in spectral efficiency by controlling the intercell interference based either on short-term or long-term channel knowledge.

The selection of the actual spatial processing scheme, i.e. the configuration and parameters of the generic processing chain in Figure 2, depends on various parameters, such as the available amount of channel knowledge at the transmitter, the physical layer mode, deployment, cell load, propagation conditions, transport channel type, traffic characteristics, BS antenna configuration, and terminal capabilities [8].

C. *Relaying*

The requirements to support potential new frequencies above 2.7GHz and higher data rates (both to the end user and instantaneously) imply a very substantial increase in the number of necessary base stations for a conventional cellular solution. Therefore it is recognised in WINNER that novel deployment concepts are needed to enable the system concept. Relaying techniques obviously provide an opportunity for cost-effective and flexible radio network deployment. Fixed relaying solutions are primarily considered in WINNER to

1. extend the coverage range of a single Base Station (BS)
2. increase the capacity at the cell border and therewith balance the capacity distribution in the cell covered by one BS.
3. cover areas which are otherwise shadowed from the BS

Deployment concepts based on Fixed Relay Nodes (FRNs) can take advantage of the stationary channel between the BS and the FRN, which can be assumed ideally as Line of Sight (LOS) and can take further advantage of directed antennas.

The FRNs should be self-configurable, which allows a deployment on demand, thus movable relay stations can be used, e.g. to flexibly extend the coverage of a BS during football matches.

In all cases the available radio resources have to be shared dynamically between the BS and its FRNs, referred to as resource partitioning. The BS is allocating parts of its resources to its FRNs. The FRN itself is in charge of allocating the resources it got assigned from the BS to its user terminals (UTs) or further FRNs.

Due to the flexible protocol architecture WINNER provides the possibility to serve the FRN-BS link with a different mode than the FRN-UT connection. This type of relay which is connected to the BS with a different mode than used to serve UT is denoted a heterogeneous relay.

The research work in WINNER has already proven that relays perform quite well based on existing air interface technologies as shown in [9] and [10]. The interested reader is referred to the public WINNER deliverables D3.1 [10], D3.2 [11] and D3.4 [12] for more research results.

Further mobile relays are considered to serve as mobile BS in vehicles like trains, busses or boats. These mobile BS are fed by the WINNER system from outside and serve their cell inside the vehicle. Thus the User Terminal (UT) sees only a fixed BS and avoids energy consuming handovers.

Another promising concept is the exploitation of the inherent spatial diversity of relay based deployment concept either mobile or infrastructure based as shown in figure 3. This concept, called Cooperative Relaying, provides a virtual antenna array by using the link between the FRN and the UT as additional path. Therefore the cooperative relaying scheme can be seen as distributed MIMO system. The received data is combined at the destination.

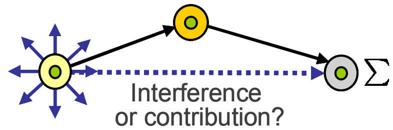

Figure 3. Illustration of co-operative relaying

D. Multi-mode protocol stack

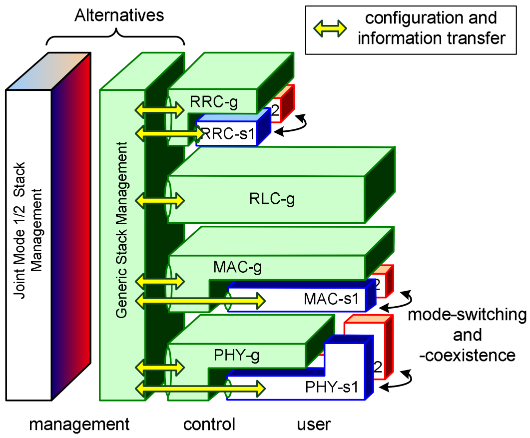

Figure 4. Multi-mode Protocol Reference Architecture

The framework that integrates the different radio technologies with the protocol stack into a common adaptive radio platform is provided by the multi-mode architecture shown in figure4. This allows an efficient integration, co-operation and co-existence between common (generic) parts and parts which require separate modes. This multi-mode stack is jointly managed and operated by the Stack Management, which enables cooperation and handovers between modes. This concept is applied to all the logical nodes in the system including user terminals, base stations and relaying nodes. Further details on the multi-mode protocol architecture can be found in [13].

V. Conclusions

Within the context of B3G research the WINNER project is developing a single new ubiquitous radio access system concept. The system will be adaptable to a comprehensive range of mobile communication scenarios characterised by differences in coverage, radio environment, spectrum, services, business models and user needs. WINNER has developed an adaptive radio interface based on a common set of scalable parameters with FDD and TDD physical modes defined to enable an efficient exploitation of spectrum allocations and adaptation to different coverage scenarios. Key enabling technologies of Generalised Multi-Carrier Modulation, spatial processing, relaying and the protocol architecture have been introduced.

WINNER is now working on the detailed development of all the system components leading to trial activities in the future.

Acknowledgements

This work has been performed in the framework of the IST project IST-2003-507581 WINNER, which is partly funded by the European Union. The authors would like to acknowledge the contributions of their colleagues.

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