

NGWN BRIEF for 2nd June 2006 London Meeting

1. Background

A number of initiatives are happening in the communications area.

We have the Mobile VCE which you will all be familiar with from presentations, and their website. There are a number of other major initiatives such as 3CR at Bristol, InfoLab21 at Lancaster, the Leeds Bradford Centre for Industrial Collaboration in Wireless Technologies, recently launched IAT at Swansea, and coming out of Cambridge-MIT activity is a possible new Communications Research Network (CRN).

In addition to these academic initiatives, in Scotland the ITI Techmedia is sponsoring technology transfer in wireless systems such as UWB, where it is funding a £6M+ programme (but the research element here is quite a modest percentage of the total).

Further in the DTI Technology Strategy Board's (TSB) first annual report (http://www.dti.gov.uk/technologystrategy/Technology_Strategy_Board_Annual_Report_2005.pdf), the DTI is formulating medium term strategies for each of the seven key technology areas covered in "A Call to Action" that the TSB released at the same time. (http://www.dti.gov.uk/technologystrategy/TSB_Call_to_Action_November_2005.pdf).

The topics identified in the "ICT" section of the Call to Action have been reorganised into the following six topics:

- security and trust
- grid computing
- intelligent systems
- communications technology
- pervasive computing
- modelling and simulation.

This is being followed up by a number of Knowledge Transfer Networks (KTN) and at the present time discussions are ongoing between Mobile VCE and CRN to bid for DTI funding for a "wireless communications related activity", given that DTI money is open.

Mobile VCE is really concerned that the UK wireless community needs to be much more proactive on an international scale to remain competitive with developments in Japan (YRP), China and Korea, as well as WWRF, mobility expert advisory group, and they would eventually like to assist to form a (UK) National Initiative with industry, academia and government/Ofcom etc. all contributing.

Within this context the NGWN committee feels that we need to keep stimulating new academic research via the EPSRC and its ICT committee, hence the following brief presents some initial ideas on topics that might be appropriate to bid for in such a new EPSRC programme.

2. Challenges in Future Communications Systems

This is a preliminary example of possible ideas or topics, but the list below is really not sufficiently visionary or active at “pushing the envelope” on really new exciting topics which need to be investigated as future research programmes.

A. Enhancing cross layer optimisation

Source Coding

During the last decade various standards for digital source coding of multimedia signals have been set. This includes speech coding by the adaptive multirate codecs in GSM and UMTS, the MPEG standards for audio coding and H.264/AVC for video coding. These are based on more than twenty years of research, and it is unlikely that major new source-coding paradigms will emerge in the near future. There is ongoing theoretical research, however, on how to approach the **theoretical limits given by the rate-distortion function** of information theory.

Nevertheless the standards allow for developments such as improved auditory models in an audio encoder or post-filters in the decoder without violating the standard. Hence research in **perceptual models**, in particular for audio and video signals, would be very important. For example it is known that distortion in an audio signal is perceived to a much lesser extent when the accompanying video sequence is changing rapidly. Research in this direction will need collaboration with other disciplines such as psychology.

With the move towards packet-switching in wireless systems, new source-coding problems have emerged. As well as bit errors within packets, some packets might not be received at all, requiring mechanisms for replacing them. This is especially difficult for delay critical applications such as voice transmission. A promising approach here is to design the encoding scheme to allow for packet loss. This includes strategies such as **multiple-description (MD)** or **embedded coding**, in which a basic quality level is guaranteed, and additional packets provide improved quality. These ideas are not new, but have not yet been fully implemented in practical schemes.

Lossless source-coding research is also now a fairly mature area: methods exist (and are in use today) which perform close to the theoretical limits with moderate complexity. Ongoing research in the field has recently concentrated on methods based on **Low-Density Parity-Check codes** with iterative decoding, and use, for example, a decoder at the encoder to check whether the reconstruction will be correct. These schemes are self-adaptive in rate, have a residual error rate of zero and can even be included into channel error protection – thus they represent a combination of source and channel error control.

Another emerging technique is **distributed source coding**: to reconstruct a source signal at any node in a network with low storage requirements at the nodes and small reconstruction delay. This is also related to **network coding**.

Channel coding

Since the early days of information and coding theory researchers and designers of error-control systems have striven to obtain performance close to the fundamental Shannon limit with feasible implementation complexity. The invention of turbo coding in 1993, and the later re-discovery of Gallager low-density parity-check (LDPC) codes, together with recent advances in small, low power and high speed coding devices, has effectively achieved this, enabling these capacity-approaching codes to play an increasingly important role in communications services.

In effect, Turbo, LDPC and related code constructions are concatenations or combinations of very simple component codes, which when iteratively decoded can achieve capacity-approaching performance, with a fraction of a dB of the Shannon limit. Practical implementations of turbo coding are starting to emerge in many applications, but their ‘error floor’ and long decoding delay (inherent to all capacity-approaching codes) makes them unsuitable in certain scenarios. Well-designed LDPC coding schemes do not suffer from an error floor, and in some cases can out-perform turbo schemes, so they are now being proposed for emerging standards. These codes perform as they do only because of a combination of the following factors: (i) very large block sizes and (ii) many iterative decoding operations (both of which introduce significant delay in decoding time especially crucial for real-time applications), (iii) low code rates which reduce data rates or increase bandwidth, (iv) complex and memory-intensive component codes and decoding algorithms.

Thus the realisation of **reliable, short codes** with excellent performance, low power requirements and high and flexible data rates is an important research objective.

So far research has been focused on the theoretical limits that capacity-approaching codes can achieve but the focus is now slowly shifting towards the determination of **practical**, low complexity coding and (especially) decoding algorithms. Thus, long term research objectives include **multifunctionality** and **reconfigurability**, e.g. adaptive low complexity capacity approaching codes for applications such as Digital Video Broadcasting. The integration of essential physical layer functions such as **equalization, synchronization, detection, channel estimation** and **multiple-access** techniques with capacity-approaching codes and iterative decoding techniques will pave the way towards multifunctional systems.

Another promising research objective is the **integration of channel and source coding**, as mentioned above. For example the distortion of parameters, due to noise, of a vector quantization system can be alleviated by channel coding using source information.

These research objectives can be summarised as **reducing the trade-offs of bandwidth and complexity requirements with respect to performance** and these can be achieved by researching channel codes themselves and by combining the coding/decoding of channel codes with other physical layer operations.

Cross-Layer Design

The move from circuit switched to packet switched TCP/IP-based networks, mentioned above, necessitates the definition of different **service classes** to properly support the requirements of, especially, delay-constrained applications. This inherently breaks with the separation of the classical Open System Interconnection (OSI) model into layers which are separately designed and optimised, since the different layers then need careful co-design to achieve the service requirements. The wireless environment further imposes new challenges resulting from the very harsh transmission environment.

Cross-layer design provides the means to tackle this very complicated problem and there is a wide range of potentially useful concepts, such as (i) **advanced scheduling algorithms**, adapting the scheduling of packets to both the service requirements of the applications and the channel qualities of every link; (ii) **rate-control mechanisms** to adapt the source coding bit rate to the channel quality; (iii) avoiding re-transmissions by **ARQ schemes** in lower networks layers for delay-limited services; (iv) **hybrid ARQ** and **incremental redundancy**. **Network coding** is an important new concept which applies combined source and channel coding techniques at the network layer, both end-to-end and at intermediate nodes of a network. It is a major challenge to identify those concepts that achieve significant gains over the classical OSI approach but which do not overly complicate the design and the implementation.

There are also major theoretical problems with multiuser networks. For example the capacity of a multiuser network is unknown, and it is even hard to define what we mean by capacity in this context. Hence, the theoretical limits for the best possible performance of a wireless multiuser network are unknown and work in this field is very important.

B. Interference Reduction in Communications

Third and fourth-generation (3G/ 4G) wireless systems call for flexible and affordable strategies that can improve the transmission rates. Signal processing techniques such as interference cancellation for direct-sequence code division multiple access (DS-CDMA) systems/ CDMA 2000/Wideband CDMA/multiple-input multiple-output (MIMO)/ orthogonal frequency division multiplexing (OFDM) or a combination of these have the potential to satisfy the higher performance requirements. While second generation systems, such as GSM/ IS-136/ IS-95, are designed for speech and low-bit-rate data, 3G and 4G cellular and local area network systems are expected to provide seamless wireless access to multimedia services and are expected to offer hundreds of Kbps for high mobility users with wide-area coverage and at least a few Mbps for low-mobility users with local coverage. Further more, the current wireless system requires coexistence of diverse services with varied traffic characteristics.

Multi-user

The evolution of these new services such as multimedia and local area networks with varied quality-of-service (QoS) requirements calls for increasing the system and link level capacity of 3G systems that are primarily limited by multiple access interference (MAI). This has prompted interest in signal processing algorithms that can mitigate interference and achieve increased capacity. The information theoretic considerations also show that the successive interference cancellation with single-user decoding can achieve all points in the capacity region of an AWGN channel. Another major idea exploited to interference mitigation is multiuser joint detection, where signals of all users in the system are jointly decoded. In particular using iterative detection and decoding receivers via parallel interference cancellation, the receiver complexity can be significantly reduced without sacrificing the performance much. The significant capacity gains achieved by such interference cancellation and multiuser detection algorithms makes them very attractive candidates for baseband receiver processing in 3G systems.

MIMO/Beamforming

While the past research focused on point-point MIMO designs/capacities of the single user system ignoring the nearby competing interferences, the current focus is to exploit the MIMO in multiuser interference-limited environment. Here the research call for MIMO system designs in the presence of co-channel interferences both uplink and downlink. Beamforming plays a major role in nulling known interference directions while maximizing the desired user signal power. Other techniques such as dirty paper coding and cooperating networks are also considered interference reduction algorithms.

Efficient RF T/R interfaces

The proposed sophisticated signal processing capabilities to support the requirements of 3G systems are also pushing for the need for efficient and high processing speed DSP. These include tasks such as high data rate signal acquisition, channel estimation for doubly selective fading channels, and resource management algorithms such as fast power control and intelligent/efficient scheduling of users. Customized ASIC designs compatible with other systems/standards with high QoS requirements are desirable. Here an emerging approach is reconfigurable software-defined radio architectures with a combination of receiver flexibility and integrated radio resource management (cross-layer). Further, software and hardware reconfigurable radios in the RF, IF also have been a focus of the current technology.

Categorization of interference:

- *Inter-symbol interference* (Equalization design)
- *Spatial interference* (MIMO receivers)
- *Multiuser interference* (Multiuser detectors)
- *Inter-carrier interference* (OFDM receivers with time-varying channels)
- *Inter-block interference* (OFDM receivers with insufficient guard interval)

All these types of interference are best handled by a maximum likelihood (ML) receiver, but this is generally too complex. Linear techniques are frequently considered, usually in the form of zero-forcing or MMSE designs, and are attractive from a complexity point of view but not very robust. Nonlinear interference cancellation techniques, including serial interference cancellation (SIC) and parallel interference cancellation (PIC), tend to be the most practical solution with the best performance, but also the hardest to analyze and grasp intuitively. There are many similarities between the suppression of the above types of interference. Without loss of generality, we focus on the challenges and possible solutions in multi-user interference cancellers in the follows.

Challenges and Possible Solutions in Multi-user Interference Cancellers:

1. **Power control:** *Unequal received power distribution* is highly preferable for interference cancellation, especially in a CDMA system. The other-cell interference can be reduced by assigning users at the cell boundaries the relatively lower required received power levels so that the interference caused to their neighboring cells is decreased.
2. **Channel estimation error and error propagation:** Inaccurate channel estimation is a problem for receivers, and worsens the error propagation in the interference cancellation, especially when the channel is highly dispersive and time-varying.
3. **Multipath channels:** Multipath channels are challenging for all wireless systems, but particularly for multi-user/MIMO receivers because each multipath component can appear to be a user of the system. The capacity of a multi-user/MIMO system is more sensitive to the channel estimation error.
4. **Iterative interference suppression/cancellation:** Iterative interference suppression/cancellation has been shown to be effective, including turbo equalization, and joint detection of error-correcting codes and interfering users, etc. However, most previous work focused on the time domain processing, which requires high complexity.
5. **Downlink Multi-user Receivers:** Uplink multi-user receivers need to suppress interference from a large number of independent transmitters, while downlink receivers should be able to suppress interference from just a few neighboring base stations, but with extreme *complexity limitations*.

Remark: The joint detection and hybrid/linear receivers are referred to as *single-antenna interference cancellation* (SAIC) receivers, which are amenable to *asynchronous* systems. SAIC techniques have proven successful in field trials in suppressing other-cell interference in GSM systems, and are promising for the future cellular system. Further research will be needed to modify these techniques for multicarrier systems such as 802.16/WiMax and low-spreading-factor 3G CDMA data systems.

On the other hand one may suggest that beam scanning antennas with nulling capabilities would be a good topic for further investigation.

C. Maximising Service Delivery

Security Issues

The number of wireless network technologies in common use continues to grow, as does the variety of scenarios/management regimes in which such technology is used. Specifically, the 'ownership' and management of parts of the network infrastructure is likely to become increasingly fragmented and chaotic, including growing reliance on peer-to-peer and self-organising systems. In parallel with this, many aspects of individual's lives are likely to be affected (even shaped) by the presence of pervasive, mobile information processing devices, typically communicating via wireless means. This growing reliance on an increasingly complex and fragmented infrastructure poses huge security and privacy challenges.

Network Aspects

Key areas requiring further research to address these issues include the following:

- Key management for self-organising and unmanaged (ad hoc) networks, including emerging work on secret key pre-distribution, and ways in which PKIs can be established in non-centralised ways.
- Design of protocols and network architectures which are inherently resistant to denial of service attacks – bearing in mind that these chaotic and self-organising systems will become a critical infrastructure.
- Design of protocols and network architectures which minimise the threat to individual privacy inherent in wireless networks, but yet which enable authorised authorities to monitor criminal activity in a minimally privacy-intruding fashion.
- Use of pre-configuration by manufacturers/vendors to increase security of self-configuring systems, without intruding on user privacy or allowing manufacturers unwarranted access to end user communications.

Service Aspects

Key areas requiring further research to address these issues include the following:

- Support for web services security in a dynamic, mobile and non-centralised system.
- Use of emerging trusted functionality on mobile platforms to support existing and new services in more secure ways.
- Methods to enhance privacy for users of distributed services in a mobile/wireless environment.
- Provision of protection to end users against novel phishing-type attacks, e.g. enabling users to distinguish between genuine and bogus service providers.

Wireless Networks

New access networks such as MANs, HANs, PANs, BANs, NEMOs and Ad hoc networks are emerging. These new networks are adding to the existing fixed, cellular, broadcast and local area networks creating a huge heterogeneous network environment. In addition, it is expected

that the future mobile user will demand access to any service/content at anywhere and any time in a seamless, reliable and secure manner. The challenge is how to support the user's demands in such a heterogeneous environment. More specifically, the scientific challenges from the Network and Service perspective are listed below, highlighting some fundamental and open research issues.

Network Aspects

The adoption of "all IP" paradigm for future wireless multimedia networks to integrate different types of traffic and therefore different applications and services, creates a number of pressing challenges that need to be resolved before the adoption of any technology that aims to provide QoS support.

- How to allocate and balance network resources among different traffic classes to accomplish the best use of network resources?
- How to allocate and balance resources among different radio access technologies, so that to minimize blocking and dropping across all radio networks?
- Finally, how to deliver the requested content/service to the user fast (low delay) and at a low cost (low cost per bit)?
- How to support seamless mobility?
- How to provide end-to-end QoS and security?
- How to use network including radio resources efficiently in such heterogeneous network environment?

Service Aspects

The exponential growth of peer to peer (P2P) technology over the Internet has recently created a need to extend this paradigm for mobile networks. The special characteristics of mobile wireless networks, such as highly variable connectivity, radio network resource constraints, limited battery lifetime and heterogeneity of wireless networks brought new challenges for research in Mobile P2P (MP2P) computing.

- How to deliver context-aware and location-based services/contents to the user efficiently?
- How to hide complexities of heterogeneous access networks, devices, service/application platforms and device operating systems from the user?
- How mobile user location can be embedded in mobile P2P services?
- How we can design efficient resource and service discovery mechanisms for handheld wireless devices with limited battery lifetime?
- What is the effect of mobility on the overlay MP2P architecture?
- What are the new business models that can emerge in this new environment where mobile operators, content providers and third parties compete for delivering services to the mobile user?

Multimodality

Multimodality will provide a more natural way of using mobile devices. This will enable the user to control the device by making calls, requesting data, or sending messages by speech, touch (using a keypad or stylus), or both speech and touch simultaneously. Users will also be able to receive information via text or voice and graphics, regardless of how the message was originally created. They will be able to change their method of interaction (visual, speech or touch) at any

time without having to end the conversation or data session. There are many research challenges which multimodality bring

- Interoperability with multimedia messaging services (MMS).
- Support of multimodality operation in distributed personal environments (personal content management, dynamic device management etc.).
- Scalability of multimodal operation (e.g. scalability of peer based platforms).
- Security implementation in multimodal systems (privacy, trust models etc.).
- Design and specification of natural multimodal interfaces.
- Integration of point of service negotiation for QoS, delivery mechanisms (parallel delivery), tariffs etc.

3. Way Forward

The purpose of the 2nd June 2006 meeting is to refine our ideas to form these into proposals for new work, which is not already being funded in other programmes, and then to put them to Nafeesa Simjee at EPSRC for possible future funding as a specialist ESPRC programme.