The Telecommunications Laboratory specializes in the important area of data transmission, with applications including mobile cellular radio, fixed satellite, mobile satellite, wireless systems, and telephone networks. The laboratory is also active in network traffic analysis, network performance analysis, broadband ISDN systems, network architectures, high speed DSL modems, and spread spectrum communications.

The main focus in the Laboratory is on fundamental research. Recent main achievements include optimum modulation codes for fading channels, optimum soft output detection and decoding algorithms, channel models for satellite mobile channels and adaptive receivers for code division multiple access (CDMA).

The Telecommunications Laboratory has significant research funding from competitive grants schemes such as the ARC. It is also involved in close collaboration with industry, both in Australia and internationally. The current industry funding supports a number of projects within the group. Research collaborations are also maintained with a number of international research groups, including those at the University of California at Berkeley (USA), and the University of Kiel (Germany).

Currently we have four academic staff, three research and technical staff, and a number of postgraduate students.

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**Research Projects**

**Weighted Space Time Turbo Trellis Codes**

Researchers: Branka Vucetic, Yonghui Li, Jinhong Yuan and Agus Santosoto

Support: ARC Discovery Grant, Norman I Price Scholarship and Girling Watson Fellowship

Space-time coding, carried out in both the time and space domains, is a practical technique that enables to approach the MIMO system capacity bounds. The simplest example of space-time coding is the Alamouti scheme, which has been adopted as a standard for the third generation of W-CDMA cellular radio networks and IEEE 802.16 broadband wireless access systems. It is simple to implement but has no coding gain and its performance is far from the MIMO system capacity limit. Space-time trellis codes achieve substantial coding and diversity gains and are simple to implement for small numbers of transmit antennas. Layered space-time codes (LST), with time domain coding only, achieve high coding and diversity gains but the detection/decoding is quite challenging for a large number of transmit antennas. Space-time turbo trellis coded modulation schemes, outperform the other known ST codes. All these space-
time coding schemes use channel state information (CSI) at the receiver only. Substantial further improvements are possible by exploiting CSI both at the transmitter and the receiver, as demonstrated in our recent results in MIMO systems with transmit antenna selection. In this project the performance and design of space-time turbo trellis codes with variable power across transmit antennas if both full and partial CSI are available at the transmitter will be investigated.

Layered space time codes with partial channel information feedback
Researchers: Branka Vucetic, Yonghui Li and Rushikesh Kalaspurkar
Support: Norman I Price Scholarship, Girling Watson Fellowship

Layered space-time codes (LST), with time domain coding only, achieve high coding and diversity gains but the detection/decoding is quite challenging for a large number of transmit antennas. The performance of layered space-time trellis codes can be considerably improved if the channel state information is available at the transmitter and exploited for signal weighting across transmit antennas. In this project we propose to consider joint transmit signal weighting and layered space-time codes to simultaneously optimize coding, diversity and weighting gains. We define the weighting gain as the signal-to-noise gain of a weighted space-time trellis coded MIMO system relative to a non-adaptive MIMO system with the same space-time code. The research includes the performance evaluation of layered adaptive space-time layered coded Gaussian MIMO system, design and optimization of weighting schemes and design of optimum layered codes for the optimum weighting scheme. We also consider the design of the signal weighting and its optimization at the receive antennas.

Weighted Space Time Trellis Codes for Multiple Receive Antennas
Researchers: Branka Vucetic, Yonghui Li and Agus Santoso
Support: Norman I Price Scholarship, Girling Watson Fellowship

The performance of space-time trellis codes can be considerably improved if the channel state information is available at the transmitter and exploited for signal weighting across transmit antennas. In this project we consider joint transmit & receive signal weighting and space-time coding to simultaneously optimize coding, diversity and weighting gains. We define the weighting gain as the signal-to-noise gain of a weighted space-time trellis coded MIMO system relative to a non-adaptive MIMO system with the same space-time code. The research includes the performance evaluation of an adaptive space-time trellis coded Gaussian MIMO system, design and optimization of weighting schemes and design of optimum space-time trellis codes for the optimum weighting scheme. The effect of channel estimation and prediction errors on the system performance is also considered to determine its robustness in practical systems. In a preliminary study with a non-optimum weighting scheme, new weighted 4-state QPSK space-time codes have been designed with a weighting gain of 2.25 dB and a coding gain of 0.6dB compared to the comparable standard space-time trellis code designed by Tarokh et al. Further improvements are expected for optimum weighting schemes.

Adaptive Transmission Strategies for MIMO Systems
Researchers: Branka Vucetic, Yonghui Li, Zhendong Zhou and Rushikesh Kalaspurkar
Support: DEST Grant, Norman I Price Scholarships, Girling Watson Fellowship

In wireless communication systems the channel is subject to deep fades that cause large signal power variations. Non-adaptive transmission strategies are typically designed for the worst channel conditions and require fixed power margins or very powerful coding to maintain an acceptable performance in deep fades. Obviously, in this approach the system resources are not used efficiently. If the channel state information is available at the transmitter, the system characteristics such as power, rate, coding scheme and bit error rate (BER) can be adapted to obtain the best performance. Some forms of adaptive schemes have been proposed for next generation wireless systems.

In MIMO systems in addition to time variations, multiple transmit and receive antennas introduce an additional dimension in signal processing. The aim of the project is to carry-out a general form of MIMO systems power, coding, BER and data rate adaptations in both time and space domain, that maximize the spectral efficiency. A general case adaptive system is formulated as a non-linear optimization problem with non-linear constraints. A systematic study on the spectral efficiency variations by optimally varying combinations of the system parameters and a trade-off analysis is provided.

Iterative Receivers for Multi-path MIMO Interference Cancellation
Researchers: Branka Vucetic, Yonghui Li, Chakree Teekapakvisit, Joseph Cheueh and Osamu Takyu
Support: Keio University Fellowship, ARC Grant, Girling Watson Fellowship

The performance of all practical wireless communication systems, including cellular radio and WLANs, is limited by interference. There are various sources of interference, such as multiple access interference caused by non-orthogonal code sequences in Coded Division Multiple Access (CDMA) systems, signals transmitted from different antennas in layered space-time coded systems, or multi-path propagation. Higher data rates imply that the signal will be increasingly prone to destructive effects of frequency
selective fading caused by multi-path propagation. This phenomenon is even more pronounced in MIMO systems, as multi-path interference consists of multiple echoes of the desired signal as well as echoes of the signals from other transmit antennas.

A conventional approach in reducing multi-path interference is by RAKE receivers. Though it is effective in CDMA systems, in space-time coded CDMA systems with a large number of multi-paths, the residual interference is considerable.

In this project we derive a new iterative receiver for layered space-time coded systems over frequency selective fading channels.

**MIMO Radar Communications**  
**Researchers: Branka Vucetic and Abner Ephrath**

The application of MIMO principles in wireless communications resulted in enormous spectral efficiency and performance gains. In today’s radar systems single receive antennas are used for both transmission and reception. In a preliminary research, a realization of MIMO radar systems has been explored. The MIMO part of the system is based on an un-coded layered system with multiple transmit antennas, while the radar signal generation is standard and based on phase modulation. The space-time divider splits a long and complex radar pulse into n “slices” in time, where n is the number of transmit antennas, and each “slice” is directed to a different transmit antenna. The signals transmitted simultaneously from various antennas, propagate over independently scattered paths and interfere with each other upon reception. The received signal for a particular transmit antenna, contains interference from other transmit antennas. In addition, there is inter-symbol interference (ISI) caused by multi-path and clutter. Each receive antenna gets a linear combination of the signals from all transmit antennas. In order to recover signals sent from each transmit antenna, the detector carries out multi-stage interference cancellation by making interference estimates and removing them from the received signal.

**Generalized Design of Space Time Block Codes**  
**Researchers: Yonghui Li**  
**Support: Girling Watson Fellowship**

Alamouti has proposed a simple space time block codes (STBC) for two transmit antennas, and it is generalized to an arbitrary number of antennas by Tarokh. A space time block code can achieve a full diversity order, but no coding gains. To improve the performance of STBC, further optimization is necessary by using super-set partitioning. The signals transmitted from two transmit antennas construct a super constellation, represented by the Cartesian product of the two constellations, thus the traditional super-set partitioning algorithm can be applied to partition the super-set into subsets with fewer points and construct a new trellis. The trellis coded signals are then coded by the traditional STBC. The proposed scheme can achieve not only a full rate and a full diversity order, but also an additional coding gain.

Furthermore, it is proposed to develop STBC using lattices, along with the design of STBC with partial channel information feedback, product STBC codes with iterative decoding and a simplification of the decoding algorithm by using sphere decoding.

**Design of Space Time Codes for Broadcast Channels**  
**Researchers: Yonghui Li and Branka Vucetic**  
**Support: Girling Watson Fellowship**

The downlink in cellular radio systems is critical in mobile Internet system design, due to high demands for information downloading. This link is an example of a broadcast channel (BC). It has been demonstrated that if the transmitter, but not the receiver, of a BC channel has perfect knowledge of additive Gaussian interference, the capacity of the channel is the same as if there is no interference. If the transmitters can co-operate, coding for non-causally known interference can be used to suppress unwanted signals from other transmitters. This scheme is called the Dirty Paper Coding (DPC). It implies that by using this type of pre-coding at the transmitter, it is possible to send messages from the transmitter to various receivers, simultaneously and in the same frequency band, and thus substantially improve the spectral efficiency. This result, due to Costas, was published in 1980, but it has not attracted much attention in the research community, as the proposed pre-coding scheme, is very hard to implement. It requires a brute force search of the entire space of the system input covariance matrices that meet the power constraint. In this project we designed practical pre-coding schemes in wireless downlinks, based on coset codes, that would approach the capacity of MIMO BC. We also develop space-time coding techniques for BC.

**Ultrawide Band Communication Systems**  
**Researchers: Branka Vucetic and Yang Tang**  
**Support: Norman I Price Scholarship**

Wireless Ultra-Wideband communications systems enable high data rates with lower power consumption and have emerged as an exciting technology for the multimedia application. As the UWB communications systems are required to operate in multiple-user and dense multipath environments, the multiple access interferences (MAI) and intersymbol interferences (ISI) induced adversely effect system capacity and performance. A novel multiuser detection scheme for asynchronous Ultra-Wideband impulse radio systems is demonstrated based on the double stages block-spread code-division multiple-access (BS-CDMA), which successfully maintains the code orthogonality at the receiver under the asynchronous environment. As a result, the MAI are completely mitigated.
In order to efficiently eliminate the ISI, the UWB channel is modeled as a block circulant matrix such that the Fast Fourier Transform (FFT) based equalization schemes are applied. The FFT-based MMSE equalization eliminates the ISI to such an extent that the system performance approaches that of an AWGN channel. As the large number order of the UWB channel, the FFT-based equalization scheme dramatically decreases the computational complexity.

**Turbo Equalization for High Mobility Communications**

Researchers: Iain Collings

This project is addressing the problem of cancelling the effect of a quickly varying transmission channel, in a way which is as near to optimal as is practically possible to implement. We have proposed a new adaptive turbo equalizer (joint work with Dr L. Davis, Bell Labs) and are currently developing analysis to assist with design choices such as the trade-off between coding and pilot insertion.

**High Speed ADSL Modems**

Researchers: Iain Collings

Asymmetric Digital Subscriber Line (ADSL) modems are capable of sending data at rates up to 20Mbps, over standard telephone wires! We are currently developing new algorithms for DSL modems, to overcome the difficulties associated with sending at such high speeds (compared to standard telephone line modems, e.g. V.34 modems). In particular, we have developed new lattice-based transmission techniques to overcome amplifier-clipping. This research project is in collaboration with Dr I.V.L. Clarkson at the University of Queensland. We are also developing a hardware testbed for ADSL using the Texas Instruments TMS320C6201 DSP.

**Receiver Design for Multiuser Mobile Communications**

Researchers: Iain Collings

Future generations of wireless networks will require advanced multi-user receivers to cancel the effect of high levels of mobility, interference, and noise. We are developing and analyzing a number of aspects of future generation receivers, such as iterative and adaptive MMSE receivers (joint work with Dr J. Evans at the University of Melbourne), and low complexity synchronization and equalization techniques.

**Receiver Design for 4G Mobile & Wireless Local Area Networks**

Researchers: Iain Collings

Future generation mobile communications and WLANs are expected to use transmission technologies such as orthogonal frequency division multiplexing (OFDM) and multicarrier multicarrier code division multiple access (MC-MC-CDMA). We are developing and analyzing new receiver designs, as well as deriving theoretical performance measures for such techniques.

This is joint work with Prof. M. Honig at North Western University, USA.

**Quality of Service in 4G Wireless Network**

Researchers: Guoqiang Mao, Lixiang Xiong

4G wireless network is going to be a high speed, IP based network, supporting a variety of services and seamless mobility between different access technologies (e.g. wireless LAN, W-CDMA). Providing Quality of Service (QoS) demanded by the multimedia services in the 4G network is a challenging problem.

This project will investigate QoS solutions in the 4G network. The objective of this research is to provide robust and uniform QoS to multimedia services across heterogeneous networks in 4G.

**Network Traffic Modelling and Performance Analysis in the Presence of Traffic Self-similarity**

Researchers: Guoqiang Mao

It is well known that some characteristics of network traffic fall beyond the conventional framework of Markov traffic modelling. Despite the recognition of the existence of self-similarity, little agreement has been reached on its impact on traffic modelling and performance analysis. Clearly the impact of self-similarity would not be as severe as indicated by some pure theoretical analysis considering an infinite timescale. Because it is in a real network with limited time-scale range that traffic self-similarity exists and exerts its impact.

This project will investigate the impact of traffic self-similarity by both qualitatively and quantitatively determining the finite time-scale range of interest for traffic measurements and performance analysis. Then it will build a traffic model matching network traffic within the finite time-scale range and carry out performance analysis accordingly. The research outcome will benefit a lot of areas, including traffic measurements, modelling, performance analysis and multi-timescale traffic engineering.

**Multiple Time Scale Traffic Engineering**

Researchers: Guoqiang Mao

Traffic engineering makes use of a number of different traffic control mechanisms. Some examples are active queue management, admission control, load balancing and routing. These different mechanisms exist, not only because they serve different purposes, but also because they only operate effectively over one particular network timescale, i.e. packet level, burst level and connection level. Moreover traffic engineering at each timescale works separately without any coordination. A small timescale allows traffic engineering to better track traffic changes to respond to congestion in a timely manner. However, this can cause frequent route changes which can deteriorate the performance of the applications.
running over the network. In addition, traffic information has to be disseminated in the network frequently and this puts additional load onto the network. On the other hand, a large timescale can provide stable routing which is important in maintaining good performance of network applications and imposes less burden on the network for traffic load information dissemination. However, it cannot deal with short term traffic surge. Thus, in choosing between a small or large timescale, a tension exists between routing stability and capability to cope with short-term network congestion.

The fundamental problem of this dilemma is caused by using only one single timescale and can effectively be removed if both small timescale and large timescale traffic engineering can be unified into one framework as proposed here. This project breaks away from the traditional traffic engineering paradigm which takes only one timescale into account to a new paradigm which takes multiple timescales into consideration. In this project, we plan to investigate a new architecture where the long term traffic control decisions are made centrally while the short term ones are made distributively. A challenging research problem is to ensure that these decisions work together to enhance the overall network problems rather than working against each other.

**Closed-loop Connection Admission Control Scheme**

Researchers: Guoqiang Mao

Connection Admission Control (CAC) is a preventive traffic and congestion control mechanism. It is essential for providing Quality of Service (QoS) supports required by multimedia applications. Currently almost all CAC schemes are open loop. Its performance relies on accurate traffic and network models, accurate model parameters, and accurate loss performance analysis. As a quick review of the existing literature indicates, no traffic model can be claimed to be accurate for all traffic sources (e.g. voice traffic, data traffic, video traffic) under all network conditions (e.g. heavy traffic or light traffic, LAN or WAN). Modelling errors, traffic parameter errors and errors in performance analysis are inevitable. An open-loop CAC scheme lacks the ability to account for these errors and adapt to real network environment to achieve an optimum performance.

This project will investigate a novel closed-loop CAC scheme where performance feedback is provided to CAC scheme to enable it to adapt to real network environment. The closed-loop CAC is able to overcome inherent drawbacks in an open-loop CAC to achieve better performance in a complex, changing network environment.

**On-Line Network Quality of Service Monitoring**

Researchers: Guoqiang Mao, Yanqiang Luan

For real-time network applications, e.g. voice, video, QoS requirements are very stringent. A prime concern is to ensure that there are adequate resources in the network to meet the traffic demand or to prioritize the use of resources when resources short-falls are unavoidable. Network monitoring and estimation have to be performed in order to keep abreast of demand. To provide dynamic network control and management, On-line monitoring and estimation have been employed as opposed to conventional off-line testing technique. One potential problem for on-line monitoring is that some QoS indicators are specified in terms of the probability of occurrence of certain rare events. This makes direct monitoring method very difficult. The objective of this project is to overcome these difficulties and comes up with a new scheme that can accurately monitor QoS parameters such as traffic loss, delay and jitter on line.


### Refereed Journal Papers


Referred Conference Papers


Coding with Joint Iterative Detection, Channel Estimation and Decoding", in Proc. OF IEEE ISSSTA'02, Prague, Czech Republic, pp. 308-312, Sep. 2002.


H. Yang, J. Yuan, B. Vucetic, “Performance of Space-Time Trellis Codes in Frequency Selective WCDMA Systems”, VTC'02 Fall, Vancouver, Canada, 2003


channels,” in 3rd Australian Communications Theory Workshop, Canberra, Australia, pp. 81–85, February 2002.


