Advanced DSP for Improved Wireless Access in Mobile Communications

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***Abstract* – This paper reports research activities performed as part of the UK Mobile Virtual Centre of Excellence (Mobile VCE), an industry-university research partnership conducting pre-competitive research for 4G systems. The Core 2 research programme, 2000~03, was subdivided into three work areas, networks, services and wireless access. This paper summarises some of the achievements in the wireless access work area.**

I. Mobile VCE

The mobile VCE is supported by 20 companies & UK government agencies such as the DTI and the EPSRC with the research conducted, under contract, and monitored by industrial sponsors in 7 UK Universities. This paper summarises Mobile VCE Core 2 programme achievements in wireless access at the Universities of Edinburgh and Bristol.

II. Compact Antenna Arrays

Antenna arrays (AA) combined with MIMO processing are one of the promising candidates for capacity and signal quality enhancement in wireless communications. Since the functionality of the AA is mainly based on the exploitation of the spatial properties of the channel, it is imperative to gain a better understanding of the influence of angular parameters on the performance of AA. In general, the angular domain comprises both the azimuth of arrival (AOA) and elevation of arrival (EOA). Early results [1,2] have investigated the impact of AOA on the spatial correlation (SC). However, few researchers have addressed the effect of both AOA and EOA together on the resulting SC. This analysis is important as the performance of the handset AA is also dependent on the effect of multi-path elevation since the handset could be oriented in any direction [3]. Furthermore, measurement results have also shown the significance of EOA whereby about 65% of the energy was found to be incident with elevation larger than 10° [4]. A closed-form expression for the spatial fading correlation function for a uniform circular array (UCA) in a 3-dimensional multi-path channel has been developed. The fading correlation function is expressed in terms of the AOA and EOA as well as the antenna spacing and geometry of the UCA. Verification is achieved by comparison with simulation results.

In [5], the closed-form expression for the real and imaginary parts of the UCA, spatial correlation are provided using the elevation separation (ES), angular separation (AS), mean elevation of arrival (MEOA) and mean azimuth of arrival (MAOA) parameters. As in [5], the AOAs of the multi-path components (MPCs) are uniform over a range of angles. Similarly, the EOAs of the MPCs are uniform over the same range. Figure 1 shows the SC for the UCA, between antennas (1,2) as a function of antenna spacing for different AS and ES values at 90° MAOA and MEOA. As the AS and ES increases, the SC decreases. However, the rate at which the SC drops with respect to the ES is lower than the AS case. Thus this emphasises that the impact of EOA must be considered.

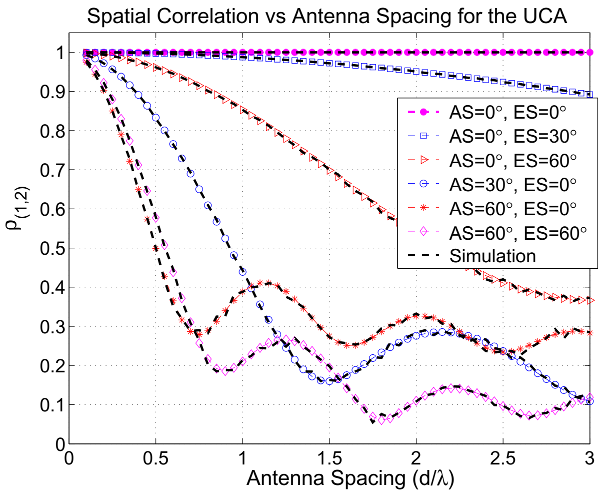

Fig. 1: Spatial correlation at various angular and elevation separation (AS/ES) values with 90 MEOA and MAOA for a uniform circular array.

III. Dynamic Directional Indoor Channel Model

This activity has developed a new wideband stochastic channel model for the indoor wireless communications systems. The indoor environment is an example of a scenario where multi-path induced time-variations arise from the movement of the transmitter, receiver or the personnel in the particular environment. Thus multi-path components (MPCs) will appear, and later, they disappear. This may be described by a "birth-death" stochastic process. Hence we have developed a channel model for the dynamic evolution of the MPCs as the mobile moves. The emergence of AA and MIMO for maximising the wireless capacity throughput by exploiting both the spatial and temporal domains has introduced a requirement for more realistic channel models. Our model is named the "dynamic directional indoor channel model (DDICM)".

A number of measurement campaigns were planned in order to characterise and implement the DDICM. The assessment of the propagation channel activities started with the standard fixed-terminals single-input-multiple-output (SIMO) measurements and moved towards the dynamic SIMO measurements. All measurements are conducted at the University of Bristol using the Medav RUSK BRI wideband vector channel sounder at a 5.2 GHz carrier frequency [6]. Figures 2&3 show typical measured channel data as obtained for these trials. Figurec 2 shows a conventional power-delay plot with reflection off a rear wall in the room while Figure 3 shows how many individual paths are actually present in the channel model.

Fig 2: Power delay plots for a dynamic indoor channel at 5.2 GHz.

Initially, a new indoor channel model which incorporates both the clustering of MPCs and the correlation between the spatial and temporal domains was proposed based on the fixed-terminals SIMO measurements [7]. MPC parameters are estimated using the super-resolution frequency domain space-alternating generalised expectation maximisation (FD-SAGE) algorithm [8] and clusters are identified in the spatio-temporal domain by a non-parametric density estimation procedure. The description of the clustering observed within the channel relies on two classes of parameters, namely, *inter-* and *intra-cluster parameters* which characterise the cluster and MPC, respectively. The correlation properties are incorporated in two joint pdfs for cluster and MPC positions, respectively. The clustering effect also gives rise to two classes of channel power density spectra (PDS) – *inter-* and *intra-cluster PDS* which exhibit exponential and Laplacian functions in the delay and angular domains, respectively.

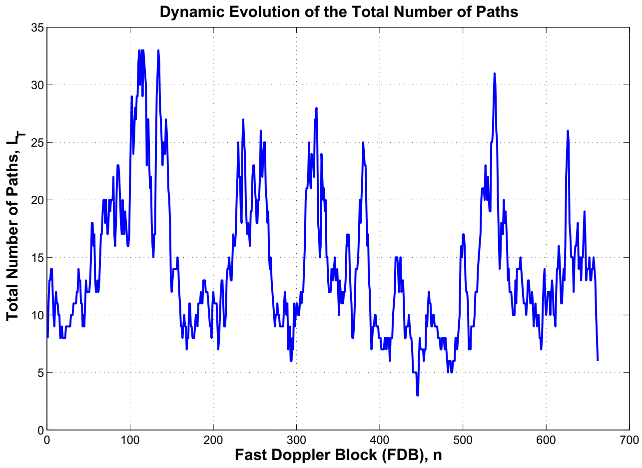

Fig 3: Evolution of the number of individual paths in the measured data.

The clustering spatio-temporal channel model is then extended to include the dynamic properties of the channel based on the concept of a Markov process. MPCs are estimated using the FD-SAGE algorithm prior to identification of path "birth" and "death" [9]. Multiple births and deaths are possible at any instant of time. Furthermore, correlation exists between these. Thus, an *M*-step, 4-state Markov channel model (MCM) is proposed in order to account for these two effects [10]. The spatio-temporal variations of paths within their lifespan are taken into consideration by the *spatio-temporal vector,* modelled by a Gaussian pdf while the power variation can be modelled by a simple low pass filter. The model has been validated by comparing key statistics of the simulations with the measured data [11].

This model is essential for accurate tracking in HIPERLAN/2 and IEEE802.11a systems.

IV. METHODS FOR MEETING USER DATA RATE REQUIREMENTS IN WIRELESS CDMA SYSTEM

This section addresses how to allocate an available radio channel resource to meet the requirements or expectations of a set of users with differing date rates. We have thus investigated a predictive resource metric region (RMR) [12,13] utilising a resource metric mapping function (RMMF), for efficient inter-working between the physical layer and higher layers. The RMR identifies the acceptable resource region where quality of service (QoS) and link quality can be guaranteed with an achievable resource margin in terms of capacity margin, the degree of confidence (DCL) of user, second-order statistics of *Eb/Io*. With predicted capacity margin and variance, DCL can deliver decision parameters where an adaptive QoS based admission control can perform well in a dynamic and predictive manner.

In an aggregated traffic stream the estimation of available radio resource can be either optimistic or conservative due to the inaccurate link quality information and the coarse estimation of overflow traffic, and thus all the resource units cannot be exploited. If we know the resource availability, i.e. the required total average resource plus the excessive resource which cannot be utilised because of stringent call admission criterion, then this information allows the acceptable resource metric region to be established on a call, a packet, or a time slot basis. This enables a resource allocation algorithm to optimise or maximise the resource utilisation.

Our approach uses the measurement of signal to interference ratio (SIR) and traffic followed by a Kalman filter based prediction. This provides predicted resource parameters for the resource scheduler to search their current position on the surface of the RMMF and to deliver the actual status of the resource usage. All of these are integrated by establishing RMR in which the calculation and estimation of resource availability are performed based on the resource region decision criteria and help the call admission decision on a call, a packet, or a time slot basis [13, 14].

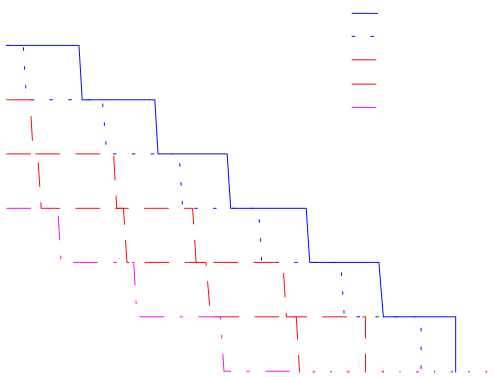

Fig 4: Estimates of the possible mix of low and high data rate users who can be accommodated on a wireless access link.

Figure 4 shows RME results for 3-rate ratios of 8/64/128 kbit/s with *Eb/Io* variance of 0-4 dB in a 3.84 MHz system bandwidth. With 0 dB variance the available capacity for mixed users is maximised. At higher variance (e.g. 4 dB) value the number of accommodated users has to be reduced considerably.

V. Adaptive User/Sub-Carrier Allocation for Multi-Carrier Based Mobile Systems

A key feature of future generations of mobile communication systems is their ability to handle multi-rate users with different quality of services thereby allowing the multiplexing of mixed traffic, such as, voice, video and data, Figure 4. For 3G systems, already deployed in Japan, South Korea etc code division multiple access (CDMA) is the preferred air-interface standard. There is a demand for much higher data rates of well over 2 Mbit/s, offered by 3G systems especially in the forward link, where users will be expected to receive high speed internet access and broadcast services. Therefore, a larger bandwidth than that allocated for 3G systems will have to be allocated for future systems along with more bandwidth-efficient transmission techniques. [15,16,17] have all suggested that orthogonal frequency division multiplexing (OFDM) and the hybrid multi-carrier CDMA (MC-CDMA) schemes exhibit superior user capacity than the conventional direct sequence (DS) CDMA technique.

We propose the use of a hybrid DS-CDMA/OFDM air interface technique combined with channel-adaptation and turbo detection. The aim of this is to provide a suitable adaptation algorithm that utilizes the channels diversity of the different users and we evaluate the capacity of such a system as well as explore the possible ways of providing different data rates and QoS.

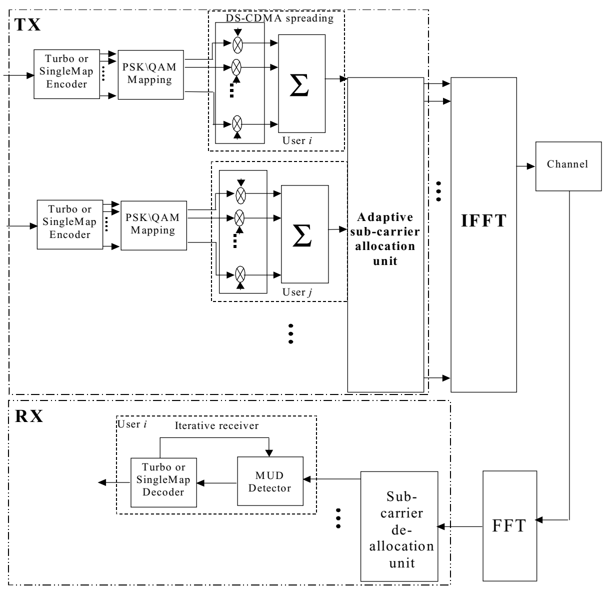

Fig. 5: Simplified block diagram for an adaptive turbo assisted DS-CDMA/OFDM transceiver.

The adaptive DS-CDMA/OFDM system proposed here is based on a downlink scenario as shown in Figure 5. The concept is to separate the different users onto the orthogonal sub-carriers so that a simple receiver detector can be used. The CDMA-spreading part of the system is used to vary the data rate of the individual users by multiplexing a sufficiently large number of symbols in parallel for each user such that its required data rate is satisfied. The allocation of the sub-carriers to the users is performed dynamically to allocate each user its best available sub-carrier using a priority swapping technique. The allocation criterion used is the minimization of the total transmission power. When higher data rates are required, random complex spreading sequences should be used to increase the data throughput irrespective of the spreading factor (since orthogonal spreading sequences are limited by the spreading factor).

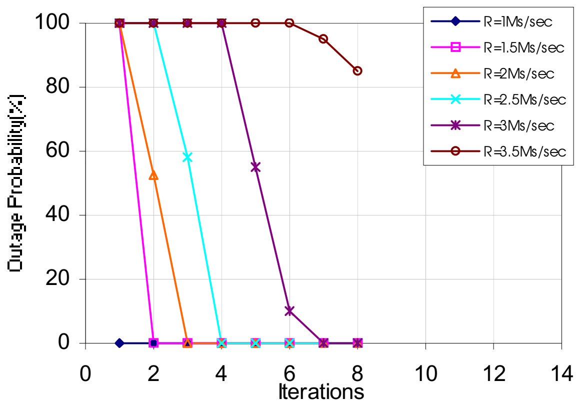

Fig. 6: Outage probability at BER $=10^{-3}$, *Eb/No*= 4dB for a successive interference cancellation – maximum a posteriori based adaptive DS-CDMA/OFDM system

The simulation results, Figure 6, are based on a combined iterative successive interference canceller (SIC) with maximum a posteriori (MAP) receiver. The results are plotted for outage probability and number of iterations between the MAP and SIC parts of the receiver. Notice that varying the number of iterations between the SIC and MAP controls the QoS. We assumed a total number of users to be 64 with an equal number of sub-carriers. Pseudorandom spreading sequences of length 4 chips were used. The remainder of the simulation parameters are based on the UMTS standard.

VI. Summary

This paper has summarised briefly a number of techniques which are expected to be widely used for wireless access in future mobile systems. The support of Mobile VCE and the many companies which fund and monitor these researches and also the DTI and EPSRC is most gratefully appreciated.

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