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# Cross Layer Interaction for IP Centric Video Applications in MIMO Broadband Wireless Networks

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*Abstract--Next generation mobile technologies must provide the throughput and QoS (Quality of Service) required for 'triple play' voice, data and media services. Novel applications are required that fully exploit the capabilities of new technology in a spectrally efficient and cost-effective manner. This paper exploits measured and simulated data to determine the range and throughput of mobile WiMAX. The benefits of incorporating advanced MIMO techniques are demonstrated together with a novel approach to channel dependent scheduling. We employ cross-layer interaction to improve range and spectral efficiency. An innovative 4G consumer application is presented that offers a non-linear user preference based approach to media-rich content distribution to mobile devices. More specifically, our solution exploits the variable QoS inherent in advanced eigen-beamforming solutions.*

## I. INTRODUCTION

Future mobile technologies must accommodate the throughput and QoS required by the 'triple play' of voice, data and media. They aim to provide seamless mobility to users, anywhere, anytime on almost any device. They are driven by the growth in wireless packet data applications. In addition to providing high QoS, high network capacity, high spectral efficiency and good interoperability; 4G will consist of an entirely IP packet switched network.

To meet the above goals it is extremely important to employ spectrally efficient channel-dependent scheduling with effective cross-layer interaction [1]. This paper uses measured data to determine the performance of WiFi and WiMAX systems in an urban microcell. Furthermore, using results from a compliant 802.16e-2006 WiMAX simulator the use of advanced MIMO techniques (including eigen-beamforming (EB)) are examined to improve operating range and capacity. Spectral efficiency gains are identified by using MIMO to transport different transport layer protocols independently over the physical (PHY) layer. This is explored as part of a channel-dependent scheduler that exploits cross-layer interaction between the PHY, MAC, Transport and Application layers. Finally, an innovative IP centric consumer application is presented to demonstrate the benefits of our proposed solution.

## II. WiFi AND WiMAX PROPAGATION MEASUREMENT

In this section we compare the performance of mobile WiMAX against the WiFi standard. As well as improving range, future standards will improve mobility, throughput and QoS. To understand their potential to deliver rich media services, we compare performance in terms of packet error rate (PER) for a 128kbps H.264 video stream. The performance of Transmission Control Protocol (TCP) and User Datagram Protocol (UDP) are compared.

The carrier-class WiMAX base-station used a 10MHz

bandwidth (2290-2300MHz) and supported 1024 subcarriers. A single 2dBi monopole antenna was mounted on the roof of a building to generate an EIRP of 32dBm. Custom logging software was created to enable the recording of GPS locations as well as throughput, delay, jitter, RSSI and PER. It also allowed 'on the fly' plotting of received data. Results showed that the range of WiMAX was better than WiFi (even at this low EIRP). This was particularly true in near line-of-sight (LoS), where WiMAX reached 400m compared to just 260m for WiFi. As reported in [2], although the range recorded from our urban WiMAX system was only 400m, it can be shown that for an EIRP of 61dBm (the maximum permitted by UK's Office for Communications) the NLoS downlink operating range increases to well over 2km. In our experiment the WiMAX UDP link was maintained over a NLoS distance of 300m. This compares with 400m using TCP (the increased robustness is a result of the TCP retransmissions). Although increased delay and jitter (and the resulting loss in throughput) may prohibit TCP based interactive media streaming, it is possible to deliver best-effort TCP data services.

Intelligent channel dependent scheduling can be used at the MAC and PHY layers to adjust and adapt to the limitations imposed by the transport and applications layers. Taking this approach we can deliver media rich interactive services in a more system efficient manner. In many consumer applications multiple services and protocols run concurrently. For a single antenna radio system these services are generally multiplexed over a single channel. In this paper we combine eigen-beamforming, intelligent scheduling and cross layer interaction to more efficiently map applications, services and protocols to the underlying physical layer.

## III. ADAPTIVE MIMO SWITCHING SIMULATION

Given scarce power and spectral resources it is important to maximise the link capacity and range. One way to achieve this is to apply MIMO techniques at the PHY layer. Mobile WiMAX supports a range of 'smart antenna' techniques including *i*) spatial multiplexing (SM) to improve the peak error-free throughput, *ii*) spatial transmit diversity (Space-Time Block Coding (STBC) and Space-Frequency Block Coding (SFBC)) to improve the operating range and *iii*) EB (also known as Singular Value Decomposition (SVD)). Eigen-beamforming operates at the sub-carrier level and converts the flat fading MIMO channel into a set of independent scalar channels. This is achieved by applying transmit and receive beam weights. Eigen-beamforming is the optimum form of space-time processing since it provides full multiplexing gain whilst also extracting full diversity gain [3]. It also provides a significant beamforming gain. If the transmission of data symbols is restricted to the strongest eigen-channel then the

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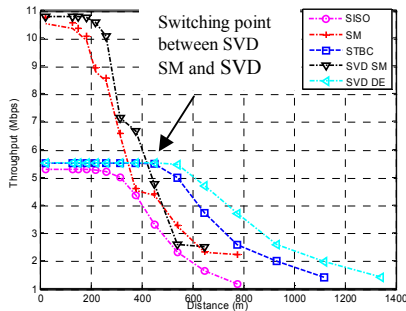


Fig. 1. Maximum throughput vs. distance for MIMO modes

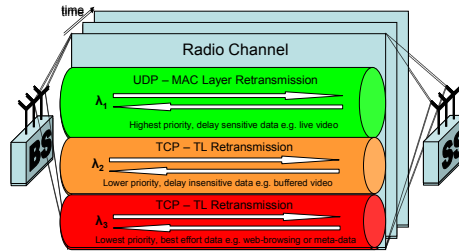


Fig. 2. Intelligent scheduling with eigen-beamforming and 3x3 MIMO

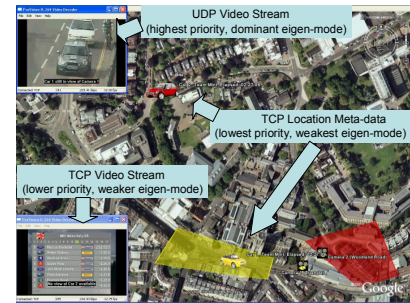


Fig. 3. Preference based video streaming

degree of diversity can be maximised at the expense of a lower peak error-free data rate (Dominant EB (SVD DE)). Alternatively data can be sent on all spatial channels to maximise the error-free throughput (SVD SM).

The fledgling WiMAX equipment used in section II used a single antenna. In the following analysis a range of MIMO techniques are compared against the single antenna case using an 802.16e-2006 simulator. We focus on the downlink (DL) of an urban microcell. The use of Adaptive MIMO Switching (AMS), in addition to the widely implemented Adaptive Modulation and Coding (AMC), is analysed in order to ensure that the most appropriate MIMO technique is always chosen. Fig. 1 shows the throughput versus distance envelope using optimum AMC for all MIMO modes for a low spatial correlation channel ( $\rho=0.16$ ). The ranges are calculated assuming the PER remains below 10%. The COST231 Walfish-Ikegami model is used to compute path loss [4]. Fig. 1 shows that SVD SM is optimum for ranges up to 420m and SVD DE is optimum for longer distances. In the case of perfect channel knowledge, SM and STBC are not selected. SVD DE increases the range from 780m in the single antenna case and 1120m in the case of SM to 1340m.

The scalar channels that result from eigen-beamforming are of varying power and quality. It is possible to use intelligent scheduling to transmit the higher priority data streams on the stronger eigen-modes and vice versa. An example of the above approach would be to transmit real-time data streams, such as UDP video, on the strongest eigen-channel(s), and non-real time TCP video (or other data) over the weaker channel(s). This approach makes efficient use of the radio resources. The concept is illustrated in Fig. 2, where  $\lambda_1$ ,  $\lambda_2$  and  $\lambda_3$  represent the channel gains of three independent eigen-channels. The dominant eigen-mode has the highest gain (and the lowest fading) and is therefore significantly more reliable. The combination of intelligent channel dependent scheduling and MIMO allows for optimization between the PHY and the MAC layers, which can be further enhanced by cross layer interaction with the Transport and Application layers.

### I. IP-CENTRIC USER APPLICATION

Next generation wireless consumer devices will be optimized to deliver rich media applications. One example, developed as part of the VISUALISE project, aims to enhance the spectator experience at major sporting events such as the

Olympics. The user's mobile device receives video streams from local wireless access points. The novelty of this application resides in the fact that the user is able to interactively nominate the competitors or sports to view. When a chosen competitor (or selected sporting event) is in view of a camera the local server instructs the mobile to automatically switch to the video stream.

Fig. 3 shows the application developed for motor racing. The top left-hand video screen shows the view when the user has elected to follow 'Car 1' and the bottom-left shows the view when 'Car 2' is chosen. It can be seen that 'Car 1' has entered the view of 'Camera 1' (in the yellow area) and thus the top screen has switched and is displaying the vehicle. 'Car 2' is not in view of either camera and hence a leader board and highlights feed is displayed. If SVD SM is used to deliver the service then cross-layer interaction could support different services and protocols on different eigen-channels. Live UDP video could be mapped the strongest eigen-channel, with best effort TCP data mapped to the weaker ones.

### II. CONCLUSIONS

This paper has shown, using measurement and simulation, the range improvements afforded by next generation mobile technologies. In particular, the benefits of advanced MIMO techniques, such as eigen-beamforming, were demonstrated. The use of channel dependent scheduling and cross layer interaction was highlighted for media-rich applications. Time sensitive data was sent via UDP over the strongest eigen-channel, while best effort data was sent as a robust TCP stream over the weaker spatial channels.

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