SOUNDERS FOR MIMO CHANNEL MEASUREMENTS

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ABSTRACT

The paper discusses the architecture of MIMO channel sounders. The semi-sequential design is contrasted with the sequential and the parallel architectures. Measurements with an eight parallel receiver semi-sequential sounder performed in both indoor and outdoor environments at 2 GHz using different antenna arrays will be presented. The parallel receiver architecture is also shown to provide simultaneous multiple frequency measurements in the 2-6 GHz frequency bands.

1. INTRODUCTION

Multiple antenna array technologies can significantly enhance the performance of radio systems. MIMO (multiple-input multiple-output) signalling techniques in particular offer diversity/multiplexing gains to provide considerably higher channel throughputs as compared to conventional single antenna systems [1]. MIMO communication has been a topic of great interest by the international research community in the past few years. Whilst space-time coding and signal processing are essential to the implementation of MIMO technologies, it is often the radio propagation channel along with the antenna array type and geometry that proves to be the major restriction in utilising this technology. Thus the experimental characterisation of such propagation channels is vital to the future development of MIMO technologies, which are intended for ad-hoc as well as for cellular systems.

In this paper we present an overview of MIMO channel sounding techniques with emphasis on the high resolution semi-sequential MIMO sounder [2] which employs parallel RF channels at the receiver and has recently been upgraded for multiple frequency band measurements for the 2-6 GHz bands [3]. The architecture of the basic channel sounder which operates in the FDD, UMTS bands is discussed and the frequency converter units to and from 2.5 GHz, 3.5 GHz and 5.8 GHz are described. MIMO capacity results of 60 MHz bandwidth measurements at the uplink UMTS frequency band (1.95 GHz) are presented for different antenna arrays. Preliminary results of simultaneous frequency measurements at the three frequencies between the 2.5-5.8 GHz bands are presented for semi-urban to rural environments. These measurements were conducted with 10-MHz bandwidth and processed with 5.7 MHz or 10 MHz for OFDM applications of wireless metropolitan area network, WMAN standards.

2. MIMO RADIO CHANNEL SOUNDING

2.1 General consideration

In general, wideband channel sounding can employ different waveforms and techniques. These vary from the simple narrow pulse, to pulse compression techniques, which provide processing gain depending on the time bandwidth product of the waveform. These sounders use either specialised equipment or readily available instrumentation such as a network analyser. The choice of the particular waveform or equipment depends on the channel sounding requirements such as indoor versus outdoor, or single antenna measurements versus multiple antenna measurements.

The main channel sounding requirements are determined by the time delay resolution, which sets the transmitted bandwidth and the maximum expected Doppler shift which determines the waveform repetition frequency (WRF). The bandwidth of the measurements is usually 300 MHz for indoor measurements or a few tens of MHz for outdoor environments (60 MHz for third generation systems). The WRF depends on the carrier frequency and the environment, with a usual sampling distance every $\lambda/3$. At 2 GHz operating frequency and for measurements in urban environments, the maximum expected Doppler shift can be accommodated within 100 Hz for pedestrian users and 250 Hz for vehicular users (maximum vehicular speeds of 42 miles/hr). The WRF also determines the maximum time delay window that can be detected without ambiguity. For indoor environments this is only on the order of a few hundred ns while in outdoor measurements this can extend up to 40 μs in city centres with high-rise buildings or suburban areas with hilly terrain [4]. Since the effective time delay window decreases as the receiver moves away from the transmitter, the waveform duration should contain a guard time, which depends on the maximum range covered in the measurements to avoid ambiguity.

Dynamic operation where the transmitter and or receiver are capable of moving during the measurements gives flexibility for mobile measurements in outdoor environments and between floors for indoor environments. An indirect requirement for wideband measurements is bandwidth compression, which enables the acquisition of the data at suitable rates. Table 1 compares the different types of sounders employed for channel measurements.

	Narrow pulse	*PRBS*	*Digital chirp*	*Network analyser*
Bandwidth/ Doppler range	High BW & Doppler	High BW, low Doppler	High BW, & Doppler	High BW, low Doppler
Dynamic operation	Yes	Yes	Yes	No
Compression	No	Yes	Yes	Not necessary
Processing gain	No	Yes	Yes	Yes
complexity	Relatively simple	complex	complex	Relatively simple

Table 1. Channel sounding techniques

For MIMO measurements these requirements are essentially the same with the added requirement of multiple transmission and multiple reception. This can be achieved in one of two possible architectures. The first uses the same single transmit (input) single receive (output) (SISO) sounder architecture with switching between antennas at the transmitter and at the receiver. To enable Doppler measurement the scanning of all antennas should be completed within the coherent time of the channel. For the 2 GHz band and an 8 by 8 MIMO system, the required WRF is 64 times that for a SISO sounder. This number is usually doubled to 128 to permit for switching transients to die out. For 100-250 Hz Doppler coverage this corresponds to waveform duration between 78- 31 μs, respectively. While the 78 μs limit provides adequate time delay window, the 31 μs limit does not enable the detection of long delayed echoes.

Switching can be avoided using parallel transmitters and parallel receivers. Reported fully parallel sounders use either narrowband multiple frequency transmissions to distinguish the different transmit antennas and FFT processing at the receiver [5] or transmit different codes [6]. The highest bandwidth reported for such measurements is 25 MHz.

An alternative to these two techniques is the semi-sequential technique, which uses parallel receivers and an RF switch at the transmitter. Switching at the receiver can be avoided with an architecture, which employs parallel channels at the receiver. For eight parallel channels SIMO measurements can still be carried out with the same WRF as for SISO systems. For MIMO measurements the WRF is increased by the number of transmit antennas. For the example of eight antennas this corresponds to 800-2000 Hz, which still gives adequate range coverage.

2.2 Semi-sequential chirp channel sounder

To avoid the limitations of the SISO architecture when applied to SIMO/MIMO measurements, the dual frequency band chirp channel sounder, [7] has been upgraded to eight parallel channels at the receiver (see Fig.1). The receiver is based on the heterodyne detector, which uses a replica of the transmitted chirp signal to compress the RF wide bandwidth. The output of each mixer is filtered with a lowpass filter whose cut-off frequency depends on the chirp parameters (bandwidth and duration) and the maximum expected time delay window, amplified, digitised and stored first on a 128 Mbytes RAM whose contents are then transferred to the hard disk. For example for SIMO measurements with 60 MHz bandwidth, 100-250 Hz WRF, and 40 μs time delay window, the bandwidth is compressed to 240-600 kHz which requires a total data acquisition rate of 1.92-4.8 MHz sampling rate. For MIMO measurements this rate needs to be multiplied by the number of transmit antennas, which is still a much lower rate than the 320 Msps or the 1 Gsps required by the RUSK sounder or the AMERRIC sounder, respectively [8-9].

To continue measurements at the two UMTS frequency division duplex (FDD) bands, the transmitter and receiver generate both bands simultaneously. At the receiver, the two bands are switched every sweep where each band can be received on all the eight channels.

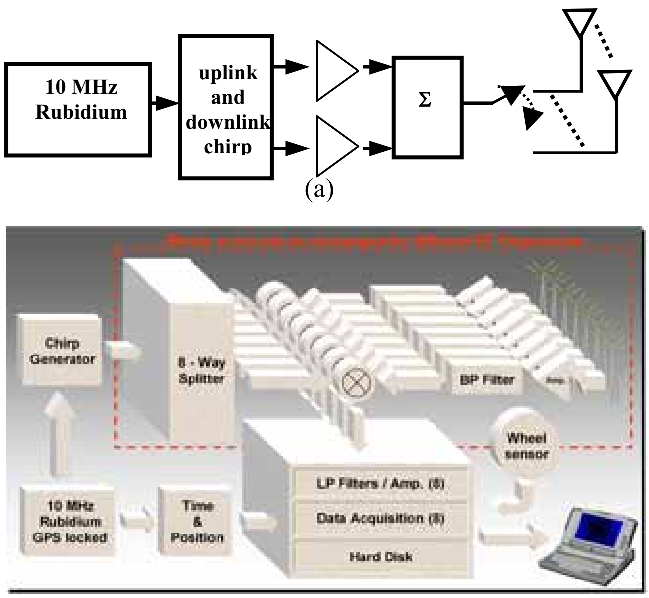


Figure 1. Block diagram of multiple receive UMTS FDD sounder (a) transmitter, (b) receiver.

Other three frequency bands (2.5 GHz, 3.5 GHz and 5.2/5.8 GHz) have been recently added to the sounder. These use the 2 GHz band as an IF for up-converters and down converters (figure 2). This enables the sounder to be used either in a MIMO configuration at a single frequency or two frequencies for 4 antenna configurations or in a SISO configuration for several frequencies. Directional antenna arrays with 45^o mounted around a circle to provide 360^o coverage were designed and implemented for the MIMO measurements at the UMTS bands in addition to omni-directional antennas. The receiver and the antenna arrays are shown in figure 3.

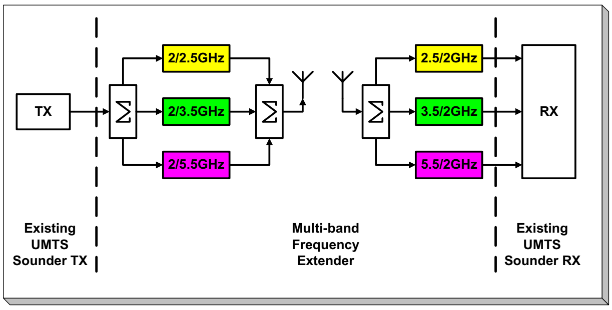
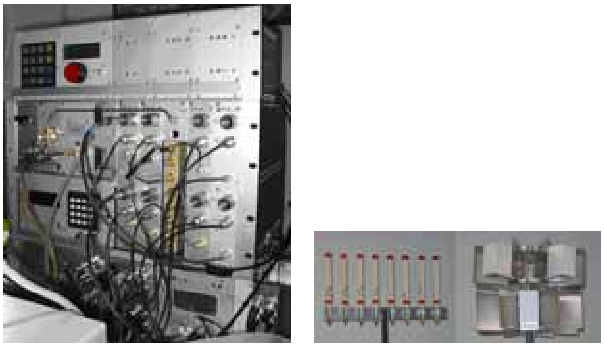


Figure 2. Block diagram of converters



(a) (b)

Figure 3. (a) Receiver of the sounder (b) antenna arrays

3. MULTIPLE ANTENNA /MULTIPLE FREQUENCY MEASUREMENTS

Measurements were performed both indoor and outdoor in various environments for both MIMO applications in the UMTS band and for WMAN in the 2.5 GHz, 3.5 GHz and 5.8 GHz bands.

The WMAN measurements were performed over 10 MHz bandwidth, where the three frequencies were transmitted simultaneously and received simultaneously using different channels of the receiver. The data were processed to determine the impulse response over bandwidths of 5.7 MHz for the 2.5 GHz and for the 3.5 GHz bands and with 10 MHz for the 5.8 GHz bands. These were used to obtain the parameters of the multipath components above 20 dB threshold for a tapped delay line model simulations and to estimate the time variant transfer function for OFDM simulations. Since the output of the receiver is the signal compressed in bandwidth and not in time, the time axis can be mapped into frequency thereby the required frequency range can be selected simply by taking the corresponding number of samples from the digitised data. The exact number of carriers can then be obtained by resampling the data if required. For the present study 512 carriers corresponding to 5.7 MHz were obtained for the lower two frequency bands and 9.8 MHz for the 5.8 GHz band. Examples of the power delay profiles are shown in figure 4. The figure displays the differences between the bands for different locations. The number of multipath components for the three frequency bands was computed for a 20 dB threshold and figure 5 gives the CDF for the three frequency bands. The figure shows that for the 2.5 GHz and 3.5 GHz bands the number of multipath components is similar whereas more components were detected in the 5.8 GHz band. This is due to the finer resolution used in the processing of the 5.8 GHz band, which corresponded to 10 MHz resolution rather than 5.7 MHz resolution for the other two bands (resolution of a chirp sounder is inversely proportional to the bandwidth).

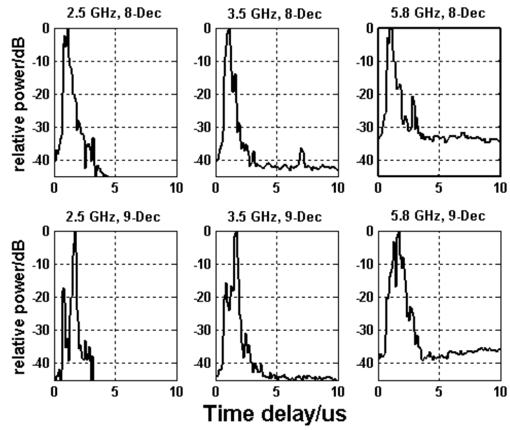


Figure 4. Power delay profiles at two different locations at the three frequency bands.

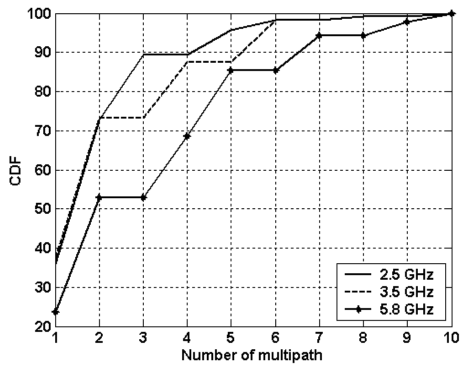


Figure 5. Cumulative distribution function for the number of multipath components.

The UMTS measurements were conducted with 60 MHz bandwidth at the uplink frequency of 1.95 GHz with 250 Hz WRF, with both arrays shown in figure 3.b. Figure 6 displays the impulse response for a 4 by 4 MIMO measurement channel using $\lambda/2$ spaced omnidirectional dipoles at both ends of the channel. The PDPs show considerable differences in the channel response from antenna to antenna at both ends of the radio link.

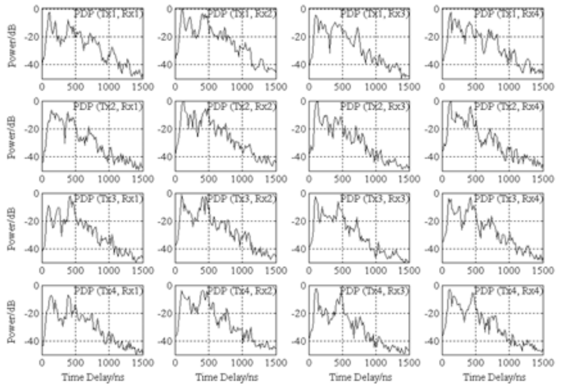


Figure 6. Multipath structure for a 4 by 4 antenna array.

The measurements were processed to determine the complex transfer function, which was subsequently used to estimate MIMO channel capacity. An example of channel capacity measurements obtained with 2 by 8 arrays where the receiver array was either vertically polarised directional circular patch array (VPDCPA) or vertically polarised uniform linear dipole array (VPULDA) is shown in figure 7 for an indoor non line of sight NLOS environment. The transmit array was a two element dipole. The transfer function was sampled at 2000 frequencies and the wideband capacity was computed as the average of the narrowband capacity using the following equation

$$C_{WB} = \frac{1}{N}\sum_{i=1}^{N} \log_2\left[\det\left(\mathbf{I}_{n_R} + \frac{\rho}{n_T}\mathbf{H}_\mathbf{i}\mathbf{H}_\mathbf{i}^H\right)\right]$$

where the transfer function for each frequency was normalised with respect to the sample norm i.e. $\mathbf{H} = \beta\hat{\mathbf{H}}$, where $\beta = \left(\frac{1}{n_R n_T}\sum_{i=1}^{n_R}\sum_{j=1}^{n_T}\left|\hat{H}_{ij}\right|^2\right)^{-1/2}$

The figure shows a slight increase in capacity for the circular patch array, which could be attributed to the reduced correlation between the elements.

4. CONCLUSIONS

The architecture of a semi-sequential MIMO channel sounder was presented and contrasted to the fully parallel and fully sequential sounders. The sounder is shown to also provide simultaneous measurements at different frequencies due to the parallel architecture employed at the receiver. MIMO measurements in the UMTS band were conducted and capacity results were presented for indoor NLOS with 60 MHz bandwidth. The results of measurements in suburban/rural environment at three different frequencies were also presented. The results are relevant to OFDM WMAN. The number of multipath components for these links was found to be between 1-8 components with 4 components being detected in more than 80% of the locations.

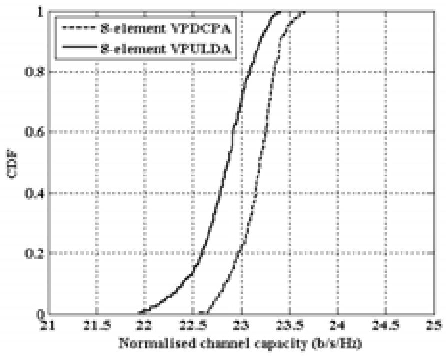


Figure 7. Capacity results for 2 by 8 arrays in indoor environments.

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