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Delayed adaptive antenna subset selection in measured wireless MIMO channels

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Abstract: Adaptive antenna subset selection can improve the expected theoretical capacity of a multiple-input, multiple-output (MIMO) wireless channel, whilst maintaining the tractable complexity of the lower order MIMO system. This paper seeks to explore the effects of delayed selection using measured indoor channel data at 5.2GHz, reflecting more accurately the situation facing a real-time system. Several selection schemes are considered and results show that delayed selection, while not as effective as instantaneous selection, can still improve the expected capacity by a significant margin.

Introduction

The large potential increase in capacity over conventional single antenna systems offered by MIMO wireless systems [1] relies upon the availability of suitable spatial channels [2]. While these channels are not always consistently present [3], antenna subset selection offers a relatively simple way to improve the chances of finding a more favourable MIMO channel, and can improve the reliability of a wireless transmission. Gains of several b/s/Hz were seen [4] in the 90% capacity¹ when selection was applied to a measured indoor 2x2 MIMO wireless channel.

This paper investigates delayed subset selection on a 2x2 MIMO radio system with four transmit antennas and four receive antennas. Selection allows the 2x2 system to gain improved capacity without requiring the extra processing channels necessary for higher-order MIMO wireless transmission. In a real system however, selection is not likely to be instantaneous, as the signal must be received before it can be processed.

Measured data

Two sources of measured channel data were analysed with delayed subset selection. Both sets of channel data were measured indoors, at a center frequency of 5.2GHz and 120MHz bandwidth, using the Medav RUSK BRI wideband multi-channel sounder. One set of data was the same as that used in [4],[5]. This was measured in the wireless lab at the University of Bristol (UoB) between two PDA form factor antenna units, as shown in Figure 1, one of which was rotated during the measurements. Each unit had two forward facing slot antennas of different polarities, a side facing slot antenna, and an upward facing slot antenna. Further details concerning these PDA units and the measurements taken can be found in [4] and [5]. Results using this data are referred to as PDA-data.

The other set of data was recorded using two laptop form-factor units, as shown in Figure 2, which sported four antennas of the same type as those used on the PDA units. Each laptop unit had the four antennas placed around the screen section, two upward facing with the same polarity, and one on each side facing outwards. The laptop units were placed in various locations within the UoB wireless lab and adjoining office environment. They remained stationary for the majority of the measurements, while the office and lab environments around them changed as people moved, simulating normal laptop usage in a typical workplace. Results using this data are referred to as laptop-data.

¹ In this paper, the 90% capacity refers to the capacity that a system is expected to achieve at least ninety percent of the time.

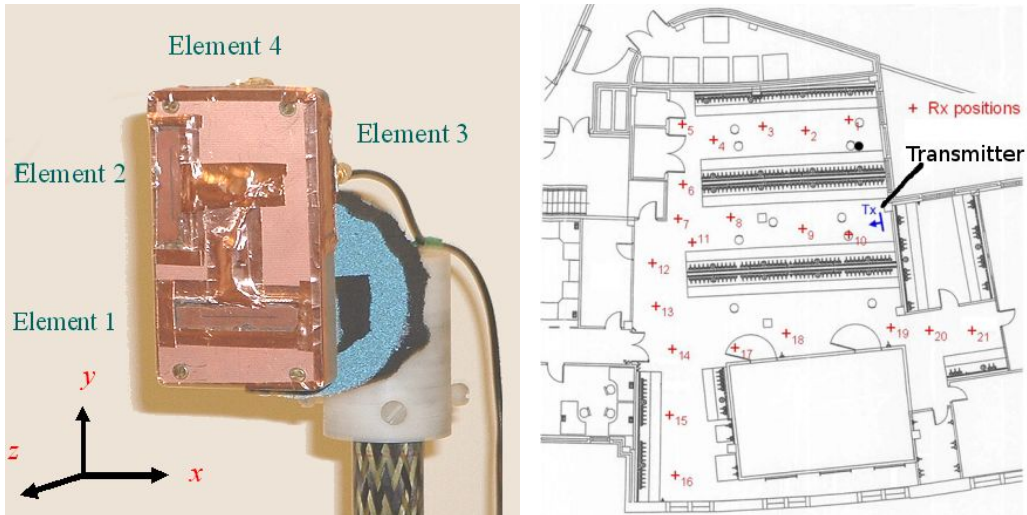


Figure 1. PDA unit and measurement location diagram

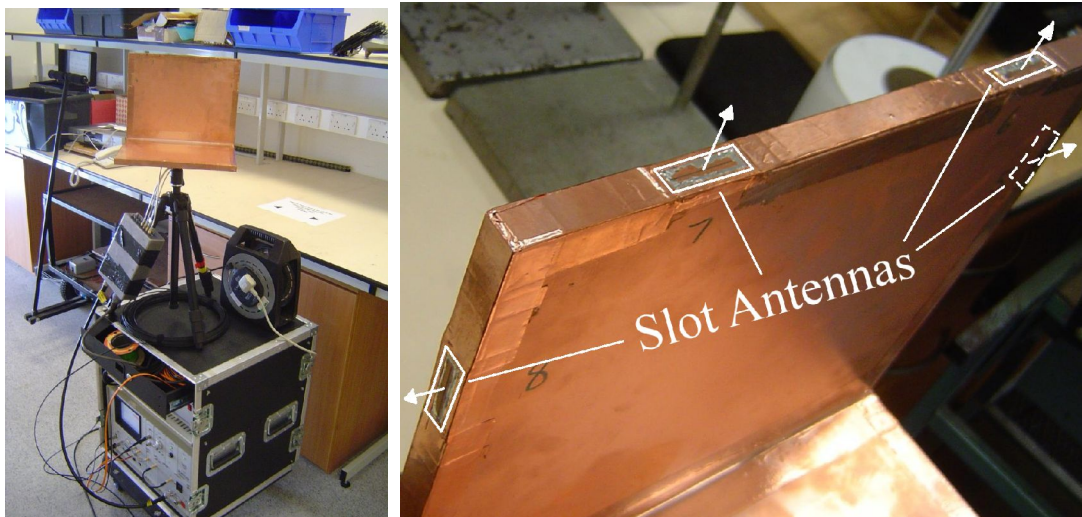


Figure 2. Laptop form-factor unit and antenna closeup.

Delayed and periodic selection

The analysis herein considered a 4x4 antenna system from which a 2x2 antenna subset was selected for transmission. The selection system is described fully in [4] and is summarised here for your convenience. There are thirty six possible combinations of 2x2 antenna subsets within a 4x4 antenna system. Three switching metrics were used to perform selection. Received signal strength indicator (RSSI) selection chose the subset with the largest total received power. Singular value decomposition (SVD) selection chose the subset giving the largest minimum singular value. Capacity (Cap) selection chooses the subset resulting in the largest theoretical capacity.

Delay was introduced into the simulation by applying the antenna subset choice from each sample to a future sample, as opposed to applying the selection instantaneously. The number of samples by which the selection was delayed was variable. The results in this paper are shown for zero and five samples worth of delay. This simulated the processing time, often required in a real system, between receiving channel information and being able to apply the knowledge gained from this channel information at the receiver.

Periodic selection was also tested where the system did not process the data to make a selection for every sample. Rather a selection decision was only made once every x samples, where x was a variable quantity. This was comparable to a real system where the radio did not have knowledge of

the full channel all of the time and was receiving on the previously selected channel subset for several samples. The radio would then update the selection by periodically sampling the full 4x4 channel to determine which antennas to use for the next group of received samples.

Results

Figure 3 displays the complimentary cumulative distribution of expected theoretical capacity for PDA-data with varying amounts of delay introduced during the selection process. The 90% capacities for PDA-data can be found in Table 1. Figure 4 shows the expected capacities of the antenna subsets for the laptop-data, and the associated 90% capacities are displayed in Table 2.

As expected, delay reduced the effectiveness of the antenna selection and reduced the improvement in 90% capacity when compared with the zero delay case. It did still show an improvement of several b/s/Hz over the average expected capacity of the fixed channels available. PDA-data, with a delay of 5 samples, achieved approximately 2.5 b/s/Hz improvement over the average channel for received signal strength indicator (RSSI) based selection, 2.9 b/s/Hz for singular value decomposition (SVD) based selection and 3.2 b/s/Hz for selection by capacity. With no delay the improvements were 3.3 b/s/Hz for RSSI, 4.4 b/s/Hz for SVD, and 4.8 b/s/Hz for capacity selection. Selection by capacity was the optimal selection method for this comparison. Longer delays typically reduced the expected capacity further, but even with 5 samples of delay a significant improvement over the average fixed channel was still seen. The resulting 90% capacities are given in Table 1.

For the laptop-data, an improvement was also observed for the 90% capacities of the selection-enhanced subsets over those of the the average fixed antenna subset values. The detrimental effect of delay on the selected laptop-data capacities was not as pronounced as is was for the PDA-data. The laptop-data typically showed a few dominant fixed antenna subsets. This was probably due to the fact that the laptop form-factor units remained relatively stationary and the environment did not change continuously as it would have done for the PDA units, which were rotated during their measurements.

Other PDA-data and laptop-data tested showed similar improvements in 90% capacity when selection was employed with and without delay. Introducing a periodic selection process resulted in similar drops in improvement when compared to selection with zero delay. The resulting expected capacities with periodic delay are shown in Figure 5 for PDA-data and in Figure 6 for laptop-data.

Table 1 and Table 2 show the 90% capacity values for PDA-data and laptop-data respectively. Figures are shown for selection with zero delay and selection with a delay of five samples. The final columns show the 90% capacity values for selection with a periodic delay of three, meaning the selected subset was only updated every third sample.

Channel	90% capacity, delay=0	90% capacity, delay=5	90% capacity, period=3
Worst case fixed	5.8	5.8	5.8
Best case fixed	9.5	9.5	9.5
Average fixed	7.3	7.3	7.3
Capacity choice	12.1	10.5	11.4
SVD choice	11.7	10.2	10.9
RSSI choice	10.7	9.9	10.4

Table 1. 90% capacity data for PDA data

Channel	90% capacity, delay=0	90% capacity, delay=5	90% capacity, period=3
Worst case fixed	5.6	5.6	5.6
Best case fixed	11.9	11.9	11.9
Average fixed	7.9	7.9	7.9
Capacity choice	13.4	13.1	13.3
SVD choice	13.0	12.6	12.9
RSSI choice	12.7	12.5	12.6

Table 2. 90% capacity data for laptop data

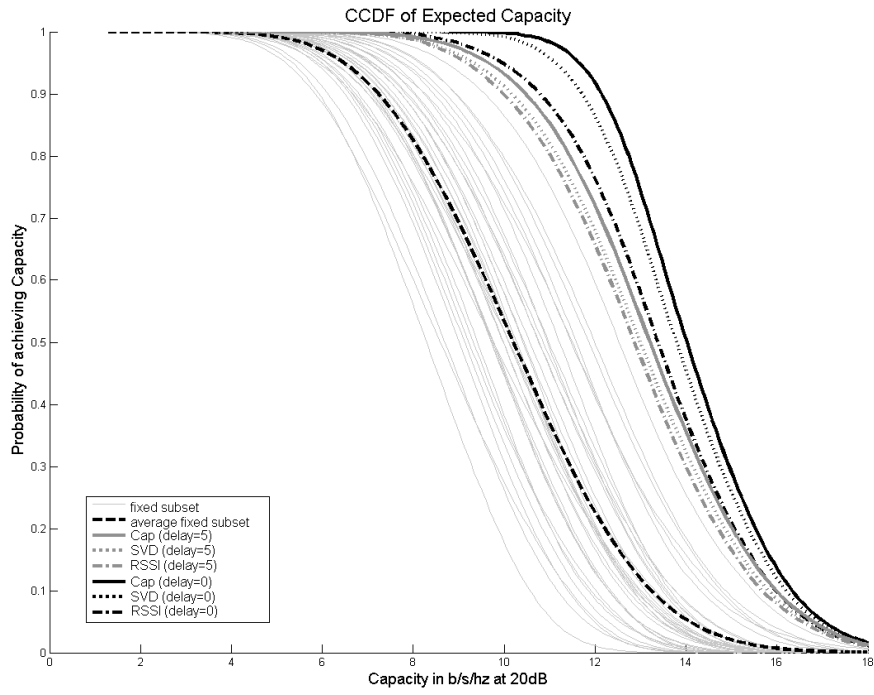


Figure 3. Expected capacity for PDA-data without delay (black) and with a delay of 5 samples (grey)

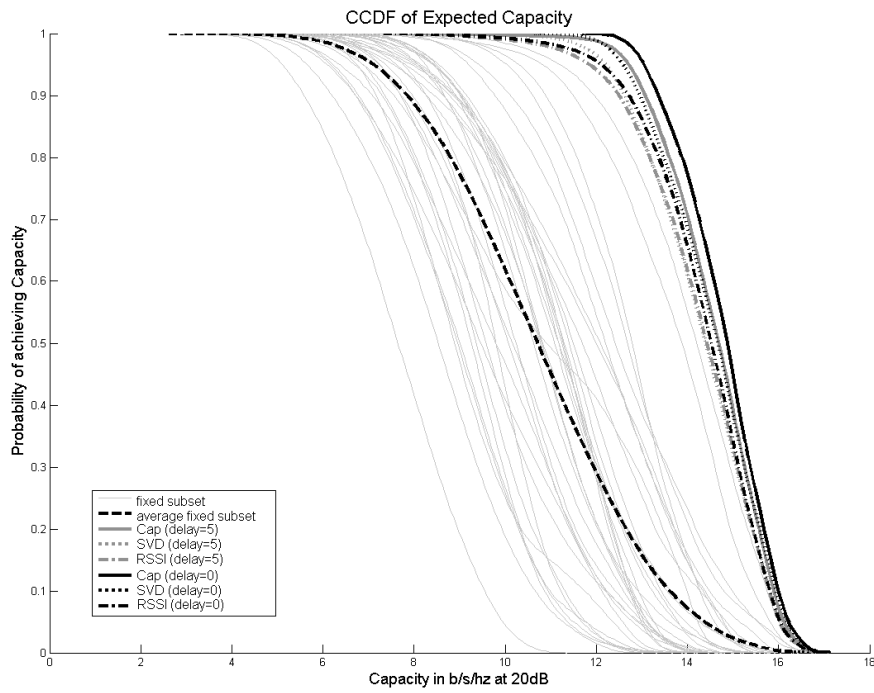


Figure 4. Expected capacity for laptop-data without delay (black) and with a delay of 5 samples (grey)

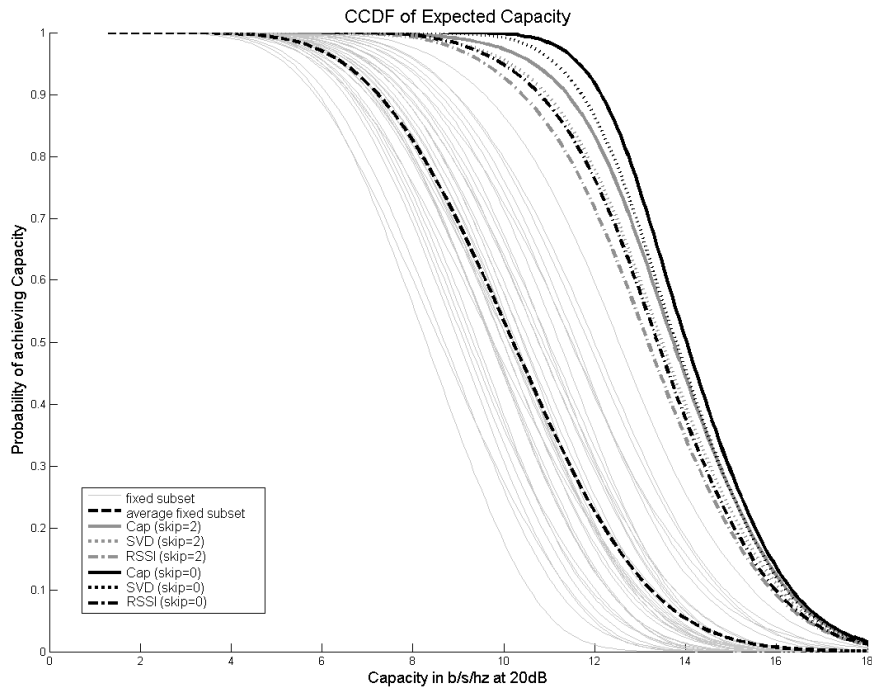


Figure 5. Expected capacity for PDA-data selection with periodic delay

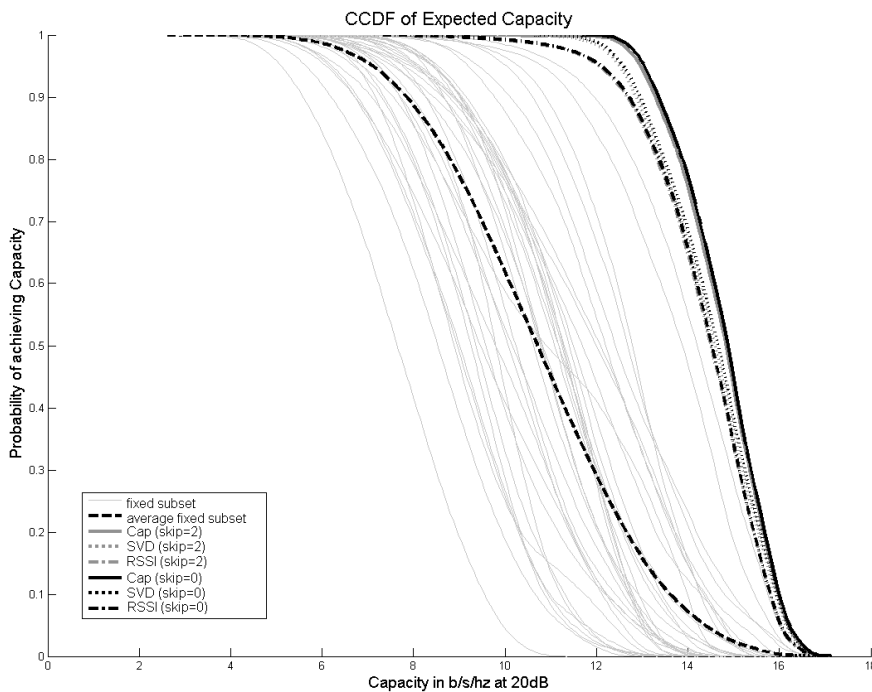


Figure 6. Expected capacity for laptop-data selection with periodic delay

Periodic selection introduced a slight decrease in improvement for the PDA-data and for the laptop-data, when compared to selection with zero delay. It did still provide a significant improvement over the expected capacity of the average fixed subset. The decrease in improvement because of periodic selection was not as pronounced for laptop-data as it was for PDA-data. The laptop-data showed less variable channels and selection decisions would have been valid for a reasonable number of samples. In some cases one antenna subset, out of the thirty-six available, prevailed almost uniquely as providing the greatest capacity throughout the measurement set. Without selection however, this subset might not have been realised, and subset selection is still a useful tool for such conditions.

Conclusions

In MIMO applications where user devices are equipped with more antenna elements than MIMO processing channels, dynamic antenna subset selection can provide an increase in expected capacity. Delayed antenna subset selection, whilst not being as effective as instantaneous antenna subset selection in all cases, still improved the 90% capacity of the measured indoor wireless MIMO channels tested by several b/s/Hz, over that of the average fixed antenna subset. For situations where the channel was not varying constantly, and where the transceiver units were relatively stationary, delayed antenna subset selection produced an improvement over the average fixed subsets almost equal to that of subset selection without any delay. These results show that dynamic subset selection could be a useful method of improving some real-time wireless MIMO systems for a minimal cost whilst exhibiting tractable complexity.

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