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Artificial Wideband Multi User Channels for Rural High Speed Vehicle to Vehicle Links

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***Abstract*—Long haul transport can be considered an obvious deployment scenario for communication between vehicles travelling in convoy, where environments will be comparable to that of a rural highway. Therefore this paper addresses antenna array techniques applicable to such circumstances, which provide little scattering to the propagation channel and little support for diversity. Only beamforming is realistically suited to increase the capacity in the vehicle to vehicle link. However, the possibility to enable multi user channels is limited in such environments since the propagation channels are highly correlated when more than two vehicle to vehicle links are in close proximity. The deliberate introduction of delay spread through wide spaced and combined multiple antenna topology thus creating an artificial wideband fading channel is proposed in this paper, which results in de-correlated vehicle to vehicle links. Measurements and experimental results are presented that demonstrate the means by which uncorrelated wideband channels between separate vehicle to vehicle links can be formed to enable multi user capabilities specific to vehicles on a rural highway.**

***Index Terms*—V2V, MIMO, Vehicle to Vehicle, Channel Model, Multi User.**

I. Introduction

UBIQUITOUS computing and multimedia is a key target of current communication technologies. One important area where this needs to be maintained is with that of high speed vehicles, to give access to facilities for people on the move. Not only is it of interest to provide broadband technologies to the vehicle but also for the purposes of identifying vehicles and exchanging information between vehicles. This would be of particular interest to public and private services for purposes such as law enforcement, traffic management (including congestion control and safety) and assisted navigation. Standards such as 802.11p for wireless access in vehicular environments (WAVE) currently under development will support applications such as these [5]. However, it is still unclear what technologies will be of benefit to both this and other standards, particularly in high speed vehicle environments where the communication channel is mutually exclusive from that of other environments considered in previous wireless local area network (WLAN) standards.

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The technological demands required for broadband communications from the roadside to vehicles and also from vehicles to other vehicles are sure to need intelligent antenna technologies not only to enable data throughput but also to handle multiple vehicle links within a close proximity. Rural highway environments are sure to require the ability for more than one pair of vehicles to communicate and possibly even one vehicle to multiple vehicles. In the 802.11n standard for the next generation of WLANs, the use of multiple input multiple output (MIMO) has been an integral part of meeting such requirements, which has naturally led to the investigation of the MIMO channel between vehicles and also from the roadside to vehicles [12] [11] [8] [16]. It is also worthy to note that these and preceding publications have paid specific attention to the unique features of vehicular environments such as the second order statistics or Doppler spectrum [2], [3] and [6]. The traditional use of MIMO has, however, had the expectation that there is an acceptable degree of multipath scattering, or scattering richness, which is not found in rural environments.

Based on previous analysis of line of sight rural highway links at narrowband in [1], we have identified that there is little scope for sufficient MIMO scattering richness both when the antenna array is outside or inside the vehicle. Thus the main focus of this paper is to consider alternative ways of enhancing the vehicle to vehicle link between two vehicles traveling in convoy (i.e. one vehicle following the other at roughly constant speed when cruising on the highway) giving particular attention to multiple user access in a correlated environment.

At first, this paper will present the channel measurement scenario for the two vehicles in convoy on the highway as well as detailed assumptions made about the antennas and other relevant factors. The channel data will then be analyzed in particular to identify the location and impact of scatterers such as passing vehicles and objects on the roadside, which is of importance to multiple access scenarios proposed and understanding of the channel being analysed. The presence of moving scatterers from other vehicles can be identified by analyzing the jitter on the channel delay spread and also the wideband dual directional channel angles of arrival and departure that can estimate the location of scatterers. The paper will then move on to discuss the possibilities of using technologies multiple access in high speed vehicle to vehicle links, in particular MIMO and orthogonal frequency division multiple access (OFDMA), resulting in the new proposed

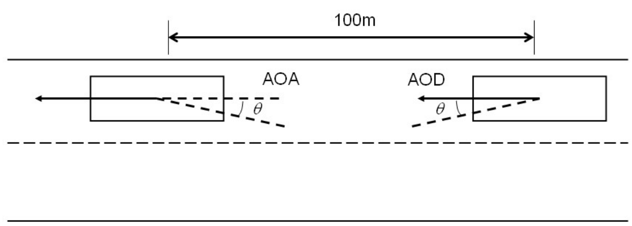

Fig. 1. Diagram of the vehicle measurement scenario on a highway in convoy

approach to wideband channel multiple access. Our approach considers the distribution of multiple antennas over a vehicle up to four meters long, where appropriate phase topologies are applied and distance between the antennas can be adjusted to enable de-correlation between multiple vehicle to vehicle channels, or from one vehicle to several others.

Fig. 2. Photograph of the motorway environment

II. Experimental Setup

The measurements undertaken were conducted in a rural highway environment, which involved the setup of a multi-antenna transmitter and receiver with detailed specifications in the following sub-sections.

A. Channel Sounder Setup

An in-house built wideband channel sounder was used to conduct the measurements [13], operating at 3.5GHz. Only four transmit and eight receive branches were used in this measurement so that a 4x4 MIMO link could be measured for receive antennas on top of a vehicle and receive antennas inside a vehicle simultaneously. This gives useful analysis identify the impact of the vehicle's interior while all other channel conditions are unchanged.

The maximum vehicle speed was 130 km/h, where vehicles moving in different directions (or temporal effects from other moving vehicles) would cause a maximum Doppler shift corresponding to double this speed, which calculates to be 843Hz. The sampling rate used by the sounder was 2540Hz in order to satisfy the Nyquist criterion. The transmitter generated a series four PN sequences of 200MHz impulses from which a 100MHz filter was applied to represent a single impulse from each transmit antenna. The PN bandwidth allowed sampling of 5ns spacing, which is important for later analysis. The time taken for a complete set of four transmit channels to be received by all eight receivers simultaneously was 1186μs, which corresponds to a change in distance of 42mm, which was found to be well within the channel's minimum correlated distance.

B. Procedure and Environment

Two vans (one transmit one receive) were each equipped with a roof mount 4 element uniform linear array (ULA), oriented perpendicular to the line of travel. The elements were printed monopoles physically separated by 0.3λ. Preceding electromagnetic model simulations [14] revealed that galvanic (conducting cable) connection could be used without disturbing the array so effects of cables need not be considered. The remaining 4 elements at the receiver van were connected to a simulated laptop array antenna placed inside.

The measurement mode was set up in "burst mode" such that once the vehicles were in the correct position to measure, they would capture 500 samples of data and then there would be an 800ms break so that the captured data could be stored before another 500 sample block was captured. Therefore the results in this paper will show blocks of data each containing 500 samples of measurement corresponding to approximately 7.1m of measured distance for each block, which are separated by an arbitrary distance of 20m for clarity.

C. Measurement location

The test area was a 1.1km highway (E45) stretch in Northern Jutland shown in figure 2, bordered by two bridges with nearby entries/exits that allowed easy access to the start and stop of test track. The rural surroundings are typical for longer haul highways in Northern Europe. The vehicle to vehicle links were measured in convoy as shown in figure 1, where the transmit van follows the receive van at approximately the same speed and separation of 100m for the whole measurement.

In convoy mode, the two vans would cruise with approximately 3s delay between them at a measurement speed of 130km/h. There were no obstructing vehicles between the two vans, thus providing good line-of-sight (LOS) conditions between the two vehicles though vehicles did have the opportunity to overtake in a lane to the left of the vans. All measurements were taken at a point far away from the two bridges whereby the results would be repeatable within around $\pm$100m of the point of measurement and no large static objects (such as buildings or bridges) are assumed to be present.

D. Antenna Pattern Analysis

3D Antenna pattern measurements were conducted in an Anechoic Chamber with the inclusion of a large ground plane comparable to that of the roof of the two vehicles in order to determine the range within which the antennas used were suitable. It was found that the antennas had a suitable beamwidth with low cross polarisation at $\pm30^o$ in the forward

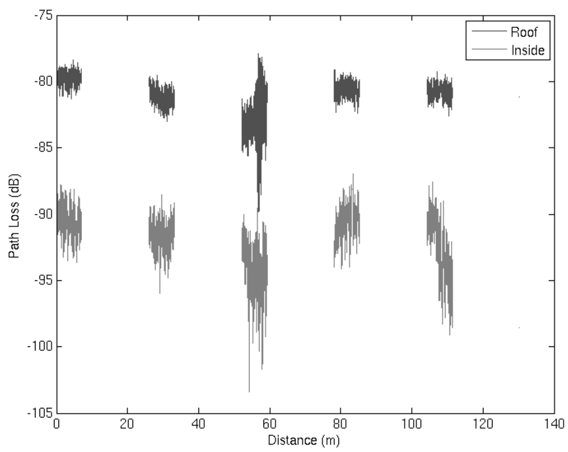

Fig. 3. Comparison of the path loss distribution for one data block both on the roof and inside the vehicle for convoy measurements

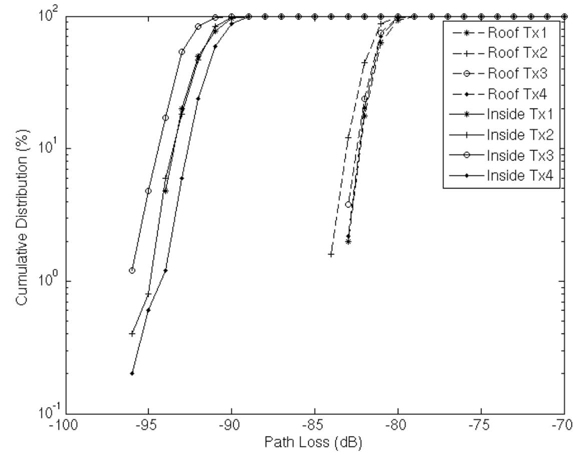

Fig. 4. Comparison of the path loss distribution for one data block both on the roof and inside the vehicle for convoy measurements

and backward directions. Using trigonometry it is possible to derive which scatterers would create rays within the antennas' beamwidths for two vehicles 100m apart in convoy. This calculates that scatterers up to 15m ahead or behind each vehicle and at least 5m to the left or right of the vehicles would be possible to characterise as delay taps if the minimum measurable delay is also considered. This is ample space for considering passing vehicles and stationary objects such as road signs on the highway, which would come close to or within the first Fresnel zone and likewise impact the channel.

III. Physical Channel Analysis

The aim of this section is to analyze the short term and long term effects on the inter vehicle channels by first considering them as a SISO link, which includes path loss, penetration loss, delay and its jitter as well as dual directional analysis of the angle of arrival (AOA) and angle of departure (AOD), which also informs the potential to use beamforming.

A. Path loss characteristics

The path loss characteristics from two separate SISO links (one to the roof of the Rx and one to the inside) analyzed in figure 3 show the measured blocks of data in convoy over distance where measurement data was obtained. Each data block represents 500 samples that were measured over a distance of approximately 14m. The vehicles had moved a distance of approximately 38m before the next block was measured (though for clarity the blocks on the images have been shortened). The results in figure 3 compare the received fading signal at one Rx antenna branch both on the roof and inside the receiving vehicle from all four Tx antenna branches (i.e. 8 sets of measurements). The most interesting result in this measurement data is that the third block of data, just after the vehicles have moved 45m on the graph (though nearly 100m in reality), indicates that there is significantly more multipath fading and deep fades caused compared to the largely line of sight links. AOA/AOD analysis will later on show that this occurrence is due to a passing vehicle or object which has created a second path.

The cumulative distribution is plotted in figure 4 from the second data block where there is not significant multipath and a line of sight. Furthermore comparisons of the roof path loss distribution and the indoor path loss distribution indicate a 10dB penetration loss, which is consistent with measurements undertaken in [9]. However, there is negligible change to the multipath which is evidenced by the consistency in the gradients of the curves in figure 4, which can possibly be explained by the fact that the extra scatterers within the vehicle are largely stationery. It should be noted from these measurements that the rear of the measurement vehicle was covered by metallic objects thus further reducing the scope of incoming scattering.

B. Short term effects

Given that both vehicles are moving at similar speeds, analysis is made at this point with regard to the diversity potential and feasibility for orthogonal frequency division multiplexing (OFDM) as well as the small packet delay jitter that would occur.

1) Amplitude statistics and Diversity potential: For initial evaluation of the diversity potential in this setup it is most appropriate to analyze the complex cross correlation at the receiver. The correlation between antennas 1 and 2, 1 and 3 and 1 and 4 were analyzed and found to be all above 0.9, even when there was extra scattering in the third block of data in figure 3. Due to the strong line of sight resulting in high correlation it is therefore not feasible that diversity can be implemented for such high values of correlation.

2) Phase effects: In the convoy case, the vehicles are set to be 100m apart from each other however, due to both vehicles not maintaining perfect cruising speed, the distance between them will vary as they move and in the order of more than one wavelength at 3.5GHz. As a result, this prevents a constant but unpredictable variation in the phase, which is a disadvantage to updating channel state information. The changing in phase does, however, cause some inherent random frequency modulation, which in turn creates a Doppler shift around the stationary point of 0Hz as shown in figure 5. A

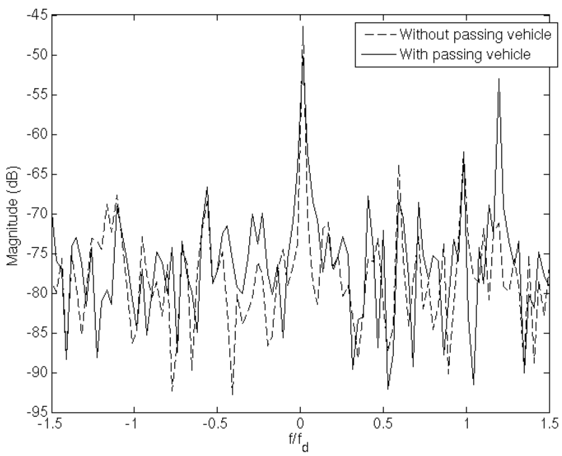

Fig. 5. Comparison of the Doppler spectrum for convoy measurements where there is a straight line of sight (LOS) and scattering from a passing vehicle

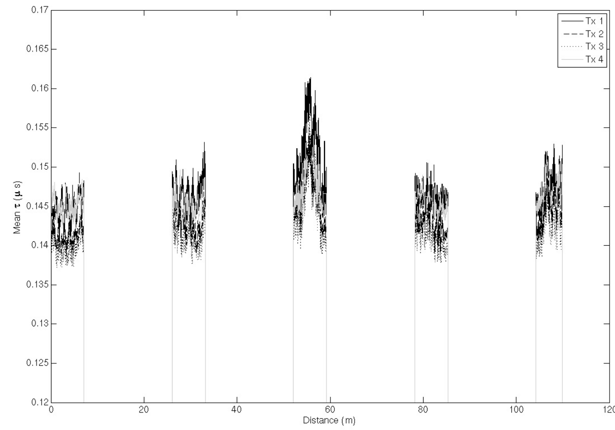

Fig. 6. Mean delay for four SISO links from four transmit branches to one receiver for the convoy measurements

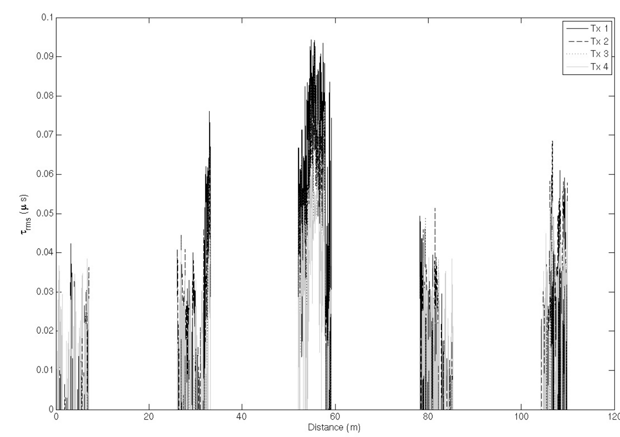

Fig. 7. RMS delay spread for four SISO links from four transmit branches to one receiver for the convoy measurements

further point to note in this figure is that in the case where there is and is not a vehicle passing, a harmonic is present at both the maximum Doppler shift and half the maximum, which is 843Hz and 421.5Hz respectively in this case. This can be explained by there being a reflection, most likely from a vehicle in front of the forward vehicle for the first harmonic and then from stationary objects in the case of the second harmonic. There is little reflection from behind the vehicle as shown. In the case of the passing vehicle, a further harmonic is observed above the maximum Doppler shift. This can be explained by the point that not only is the ray shifted by the speed of the receiver vehicle but also by the movement of the passing vehicle acting as a scatterer. It should be noted that with the sampling used there could potentially have been higher Doppler frequency harmonics, though this is unlikely given that two vehicles were not moving in the direction of each other at 130km/h. However, what is of more interest here is that the duration of such instances of high Doppler shift will be short and thus can be considered as "chirps" in the Doppler spectrum, which potentially is disadvantageous to maintaining a carrier to interference ratio for OFDM with such high values of Doppler shift [15], which would have to be compromised by extended packet lengths at a cost of available bandwidth.

3) Delay taps, timing jitter and inter symbol interference: For analyzing the wideband effects on the channel, a helpful consideration is to determine the mean and RMS delay spread and analyze the jitter as the vehicle moves [4]. Clearly by inspection of figures 6 and 7 the mean and RMS delay spreads begin to significantly increase thus indicating that there is the presence of more multipath components. It is worthy of noting in figure 6 that the four mean delay values are plotted from four transmit branches to the same receive branch. In all blocks it is noted that the mean delay for Tx antennas 2 and 3 is marginally lower than that of Tx antennas 1 and 4. It should be noted that the antenna patterns of Tx antennas 1 and 4 being on the edge of the antenna array have slightly different patterns to that of antennas 2 and 3, thus causing the direct paths to have a small offset in magnitude which in turn creates a small increase the mean delay of 0.002 μs shown in figure 6, which is considered negligible compared to the differences in delay of the multipaths. Since the vehicles are moving in distance apart in the order of $\pm 5m$ then the re is a variation in the peak delay tap and also rapid change in delay taps close to the main delay tap, thus causing a jitter on the RMS delay spread in the order of 20ns.

C. Directional channel identification

In order to ascertain the location of the multipath, we now wish to analyze the dual directional channel. As each vehicle was mounted with omni-directional antennas in a uniform linear array (ULA), this allows simple dual-direction scanning to identify scattering clusters in azimuth. The Capon method [10] can be used in this instance to analyze the data, which applies a Capon filter to the ULA channel state information to determine the angle of arrival between $\pm 90^o$ on the broadside of a ULA. However, it has been previously noted that the antennas have a suitable omnidirectionality when only $\pm 30^o$ in azimuth and thus only angles of arrival within this range can be considered legitimate. For analyzing angles of arrival and departure in the wideband case, the angular power distribution,

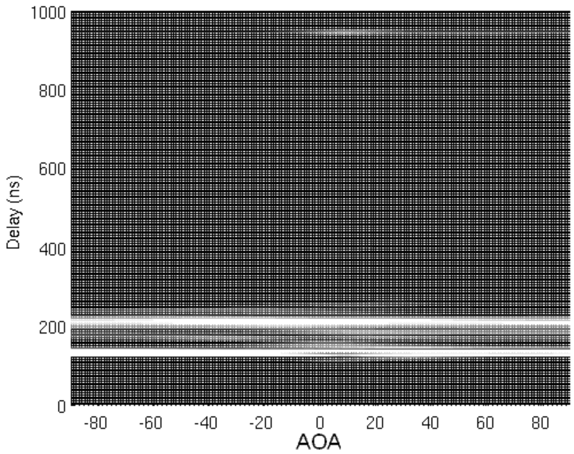

Fig. 8. Analysis of the AOA over delay taps for the convoy case when a vehicle is passing

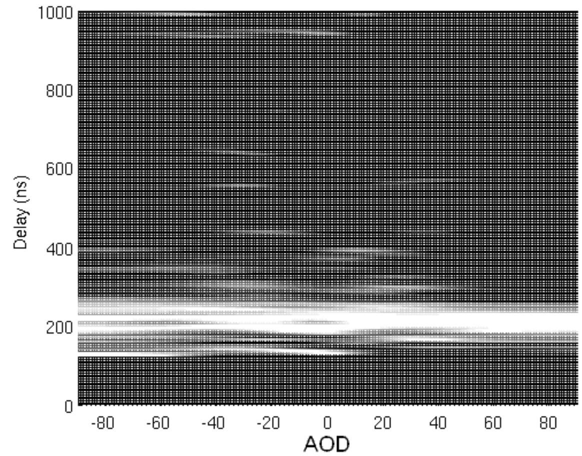

Fig. 9. Analysis of the AOD over delay taps for the convoy case when a vehicle is passing

$P(\theta)$, as a function of azimuth angle θ is derived from a Capon filter for a given time instant t, which has a delay profile as a function of τ. Thus it is possible to determine the angles of arrival (AOA) and also angles of departure (AOD) for each delay tap. Thus where θ is the angle relative to the direction of travel in the case of AOD and the angle relative to the reverse direction of travel in the case of AOA shown in figure 1:

$$P(\theta,\tau) = \frac{1}{\mathbf{a}^H(\theta)\mathbf{R}(\tau)^{-1}\mathbf{a}(\theta)} \tag{1}$$

Where the correlation matrix $\mathbf{R}$, is defined using N sample spaces at a given fixed delay tap, τ as follows:

$$\mathbf{R}(\tau) = \sum_{n=1}^{N} \mathbf{h}(t_n,\tau)\mathbf{h}^H(t_n,\tau) \tag{2}$$

and $\mathbf{h}$ is a 1x4 single input multiple output (SIMO) or 4x1 multiple input single output (MISO) vector representing the physical channel link from one vehicle to the other. This is for one time instant t, and delay τ so the vectors become four dimensional matrices with the number of samples in both time and delay as the other dimensions. For the purposes of this analysis, AOD is considered on top of the rear transmitting vehicle relative to the forward direction shown in figure 1 and AOA is considered to be on the front receiving vehicle relative to the rear direction. Therefore the AOA and AOD can be derived by applying the same Capon analysis on the MISO or SIMO vectors respectively. The beamforming vector applied to the Capon method, $\mathbf{a}(\theta)$, is a four element phasor represented by $[1\ e^{-j2\pi d\sin(\theta)}\ e^{-j4\pi d\sin(\theta)}\ e^{-j6\pi d\sin(\theta)}]$, where d is equal to 0.3 wavelengths in terms of physical separation of the antennas. In this analysis, N was set to 10 in order to compute a realizable inversion matrix, $\mathbf{R}^{-1}$.

The only point of interest to analyze the wideband delay taps in this measurement is within the third block where the multipath was observed. All the other blocks have a single angle of departure and arrival with negligible multipath components so there is therefore nothing of interest with respect to diversity. The results are shown in figure 8 for the AOA and in figure 9 for the AOD in the block of interest. Two delay taps can be clearly identified from the AOA as the first path being the direct path arriving close to 0^o and a delay of 125ns though due resolution errors in the Capon method, the peak (though not clear to identify directly from the image due to small changes in magnitude) is based closer to $+10^o$. The second delay tap is 85ns later, corresponding to the fact that is has traveled 25m further than the 100m between the vehicles. This particular delay tap is arriving at approximately -20^o. If we were to correct the errors in resolution set the direct tap to 0^o, this would set the second tap down to -30^o. If this were so, then knowing the distance between the vehicles of 100m means that by using trigonometry the scattering object can be calculated to be at a point where it is closer to the transmitting at a point of about 25m in the direction of the front vehicle, but 20m to the left in the direction of travel. For such distances, it appears that the scattering object is a large vehicle on the other side of the highway moving in the opposite direction to the vehicles in convoy. The corresponding AOD calculates to be $+60^o$, which explains the lack of resolution in figure 9 because the incoming tap is not arriving within the valid $\pm 30^o$ region. We can however, conclude from the results presented that the scattering object in the measurement data analyzed is most likely to be that of a passing vehicle.

It can therefore be concluded for the high speed vehicle to vehicle wideband channel that the most appropriate model would be that of a direct tap followed by other taps that are switched on and off at instances defined by Markov state transitions [6]. Selected taps would need to be switched on and off so that they correspond to the position for both time and angle of arrival/departure for the multiple antennas.

IV. Wideband Multi User Channel Generation

It has been shown by results presented in [1] that there is little scope for MIMO capacity in the high speed vehicle to vehicle links in our type of environment. In all instances, the second eigenvalue is on average 10dB down from the first eigenvalue and thus such multi antenna links would only benefit from beamforming gain. The scattering analysis presented in this paper shows clearly the lack of scatterers

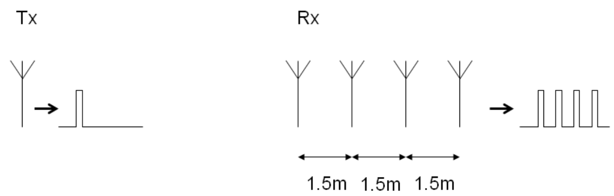

Fig. 10. Generation of artificial delay taps

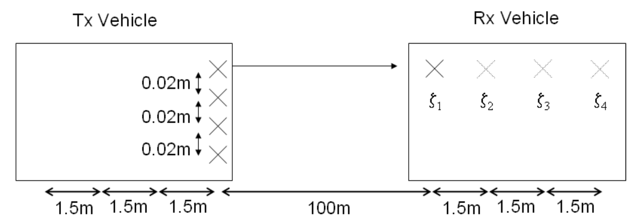

Fig. 11. Demonstration of how the topology setup used between two vehicles

TABLE I
PHASE TOPOLOGY APPLIED TO THE FOUR CHANNELS

Channel	Phase Setup
1	$\zeta_1 = 0^o$ $\zeta_2 = 0^o$ $\zeta_3 = 0^o$ $\zeta_4 = 0^o$
2	$\zeta_1 = 180^o$ $\zeta_2 = 0^o$ $\zeta_3 = 180^o$ $\zeta_4 = 0^o$
3	$\zeta_1 = 0^o$ $\zeta_2 = 0^o$ $\zeta_3 = 90^o$ $\zeta_4 = 90^o$
4	$\zeta_1 = 90^o$ $\zeta_2 = 90^o$ $\zeta_3 = 0^o$ $\zeta_4 = 0^o$

regardless of whether the transmit or receive antennas are inside or outside the vehicle. With a highly correlated channel environment such as this, beamforming does not allow ease in distinguishing between vehicles along a highway, especially when the traffic density is high. A scattering rich environment would cause frequency selectivity in the radio environment and would provide greater help to better distinguish multiple users. Scattering richness is not available, nor can it be created either within the vehicle or in the surrounding environment for a rural highway though we propose a method by which we can artificially create delay taps in the line of sight links in a way that each vehicle has a frequency selective channel that is de-correlated from other vehicle to vehicle links in close proximity. Thus we open the opportunity for multiple user vehicle to vehicle channels over a wide bandwidth.

Assuming a vehicle is over 4m in length, we re-arrange the array antennas on a vehicle such that rather than having a 1x4 linear array as with the previous measurements, the antennas are spread far apart along the length of a vehicle, or vehicle roof. For the purposes of this paper, the channels measured were shown to hold stationarity for a distance above 5m, thus it is possible that a SISO link from the measured data can be repeated four times so that the spread antennas are emulated. Therefore, the first emulated antenna represented a shift in space of 1.5m. Likewise a shift of 3m was applied to the third link and 4.5m to the fourth. Thus as illustrated in figure 10, a 1x4 channel link is created by superimposing (as a result of combining) four separate shifted delay profiles into one. The thermal noise in the measured channel was removed after choosing an appropriate threshold so as to maintain the SNR that would be obtained had the four antenna delays been measured. Thus, the resultant output shows that a scenario has been created whereby there are four artificially generated delay taps of comprable magnitude given the negligible change in path loss. The same effect could be achieved by having four transmit antennas spaced apart by the same distance and only one receive. In this paper, however, only receive mode will be considered for ease of understanding. Therefore in every case, a vehicle may transmit one impulse to another vehicle and several others at the same time, while each receive vehicle will have four antennas spaced apart (possibly differently) to receive four artificially created delay taps that may also be different.

In a case where the received power delay profile consists of four delay paths, it is going to contain significant degrees of frequency selectivity. Thus a line of sight channel link between two vehicles has been made frequency selective as a result of creating artificial delay taps from multiple antennas. A further point to note is that the receive antennas themselves can have phase weights applied to them as well as being spaced apart by different distances as illustrated in figure 11 where the four receive points artificially created have effectively each had a phase weighting applied to branches 1 to 4 labeled ζ_1, ζ_2, ζ_3 and ζ_4 respectively. Though four transmit antennas were available, only one needed to be used in order to superimpose the four SISO links. Therefore the three antennas to the right of the first receive antenna are indicated by dotted lines because they are in effect virtual array elements generated by applying a shift to the first one. This paper therefore demonstrates preliminary investigations into how the phase weights can be manipulated on two separate vehicle to vehicle links, which will have a highly correlated channel. The phase manipulation if set appropriately will in effect cause the two wideband channels to be uncorrelated.

The main analysis carried out in the results is to compare the wideband channels that are created by changing the phase at the taps, ζ_1, ζ_2, ζ_3 and ζ_4. Four different configurations of these four phases have been chosen, which are numbered 1 to 4 and their respective phases shown in table I.

In the first instance, these four channels were generated using a snapshot from the measurements in an area where there was low frequency selectivity and no scattering. Figure 12 plots the four channels as well as a SISO channel in the frequency domain where it can be clearly seen that there is substantially higher frequency selectivity. The magnitude of the complex cross correlation of the channels with differing delay taps are shown in table II, where all instances of two different channels shows the correlation to fall below 0.7, which is sufficient de-correlation to enable multi-user capabilities between channels.

The same analysis was carried out at a point in the block where the passing vehicle was causing scattering additional scattering. As seen in figure 13 the SISO channel already has some initial frequency selectivity, which does not impact on the ability to create frequency selective channels as before. It is of interest to note that there is negligible difference to the correlations of the channels compared with no scattering as shown in table III.

The results generated in this paper clarify that given the size of vehicles, there is the opportunity to exploit the highly

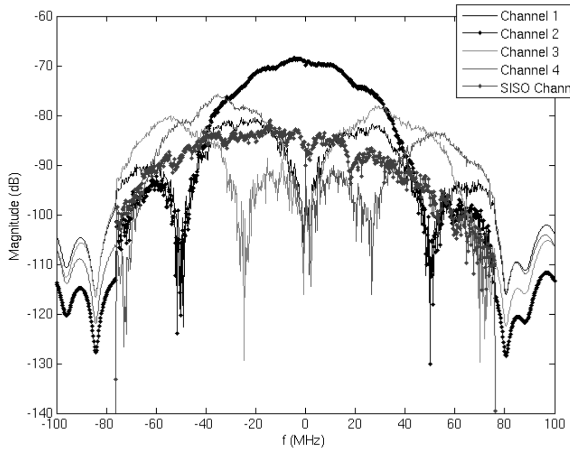

Fig. 12. Example case of the open channel with added frequency selectivity using different antenna phase topologies

TABLE II
TABLE OF THE CORRELATION BETWEEN THE FOUR CHANNELS IN AN OPEN ENVIRONMENT

Channel	1	2	3	4
1	1	0.30	0.34	0.62
2	0.30	1	0.15	0.40
3	0.34	0.15	1	0.52
4	0.62	0.40	0.52	1

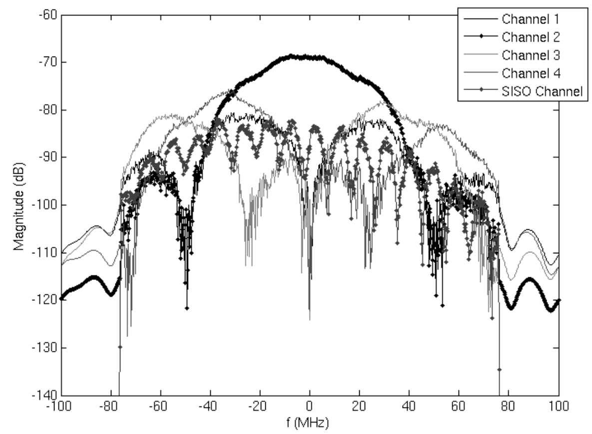

Fig. 13. Example case of the open channel with added frequency selectivity using different antenna phase topologies with the impact of a passing vehicle

TABLE III
TABLE OF THE CORRELATION BETWEEN THE FOUR CHANNELS IN THE PRESENCE OF SCATTERERS

Channel	1	2	3	4
1	1	0.29	0.34	0.59
2	0.29	1	0.14	0.38
3	0.34	0.14	1	0.56
4	0.59	0.38	0.56	1

correlated highway vehicle to vehicle links by deliberately creating wideband channels to allow multi user diversity. Another benefit of this method is that while signal to noise ratio may be compromised at a fixed frequency point, more energy is spread over the bandwidth and it enables multiple users to use the whole bandwidth simultaneously. Multiple access in a rural vehicular environment could be achieved by means such as frequency division multiplexing (FDM) or orthogonal frequency division multiple access (OFDMA). However, as has been identified earlier with OFDM, the high speed passing vehicles causing instantaneous Doppler chirps do cost bandwidth, which would include unused guard bands. Furthermore, with multiple vehicle links, synchronisation to enable multiple transmitters to sustain orthogonal frequency carriers as is required in this scenario would be problematic.

In order to exploit the de-correlated wideband channels generated under this method, the means by which the time delay processing can be applied to best achieve this for multi-user vehicle to vehicle links in close proximity is an item for further research. However, the proof that sufficiently de-correlated channels can be created simply by adjustment of the phase topology on each vehicle as well as the fact that all vehicles are different in shape and size will mean every delay topology is different on every vehicle and thus enables the possibility to generate independent channels regardless of how close or far away vehicles are. The channel frequency selectivity is dependent only on the antenna and phase topologies and it is assumed the mean power would be comparable in each branch.

V. CONCLUSION

The experiments presented in the paper reveal very little dispersion and dynamics in spatial and temporal sense, which provides little opportunity for multi element MIMO array processing both in terms of multiplexing and diversity. However, as the convoy case analyzed in this measurement for high speed vehicle to vehicle links is unique with multiple users represented as vehicles traveling at comparable speeds in a line, there is no angular discrimination between users and thus it is near impossible to distinguish between them. Instead the introduction of deliberate coded temporal dispersion via unique wideband array topologies can be placed onto vehicles that will allow them to be distinguished and marked by a unique channel. Our simple example shows that even for very low effective array taps and bandwidth as low as 200MHz, the delay resolution of array element spacings will still help code the array with respect to unique phase offsets.

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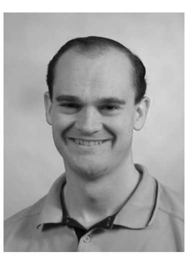

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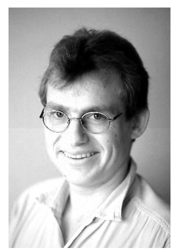

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