Keeping Mobile Communication Channels Static With Base Station Antenna With-Movements

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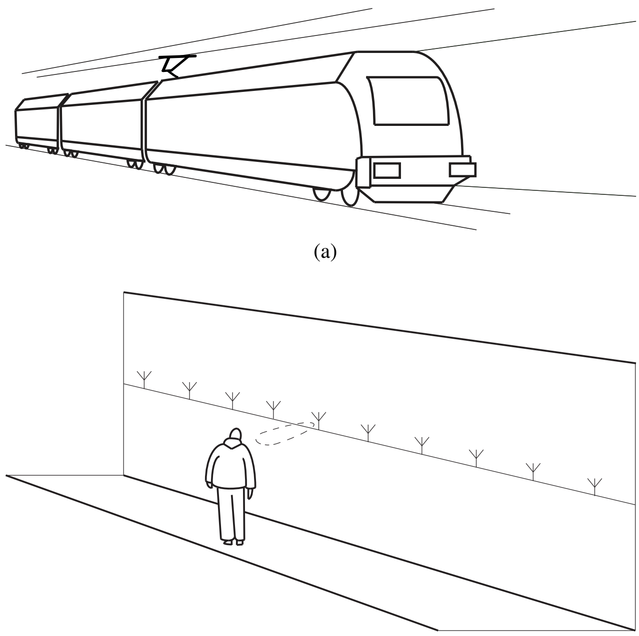
***Abstract*—Movable antenna concepts and movement solutions such as fluid antennas have recently gained traction. These schemes typically consider movements of the User Equipment (UE) antenna, either to compensate the UE's movement or generally improve the channel. The opposite approach is explored in this work. Mobile communication channels can be kept static by movements of the (usually fixed installed) base station (BS) antenna to which the communication channel is formed. The base station antenna partners with the moving UE antenna and simultaneously moves with it along the same trajectory (*with-movement*). Experimental proof-of-concept results are presented for movement along a straight line over a distance of several wavelengths. Measurements were performed with 2.45 GHz quarter-wavelength monopole antennas in an anechoic chamber. Statistical analysis and mathematical models of the results are presented. In an idealized scenario the received power shows no fading and doesn't vary with moved distance, the phase shift remains static and not longer increases with distance.**

***Index Terms*—Communication channels, fluid antenna, mobile antennas, movable antenna, radio propagation, static, vehicular channels.**



(a)

(b)

Fig. 1. Applications of moving BS partner antennas. a) Many vehicles move along predefined paths. Trains move along tracks and cars move along roads. The tracks, overhead lines and sound barrier walls are translation invariant to the trains (antenna) movement. b) A pedestrian walks along a sidewalk. A distributed antenna system follows the pedestrian. The sidewalk and wall are translation invariant to the trajectory of the user and BS antenna. All images

I. Introduction

Changing wireless communication channels are a serious performance inhibitor for modern wireless communication schemes. The antenna movements in mobile and vehicular scenarios are major causes of changing channels [1], [2], [3]. For example, two-path propagation results in deep spatial fading [4] and a small scale fading environments only manifests as fast-fading at a receiver when the receive antenna moves through it. Compensation of movement effects on a physical basis are already successfully in use in radio applications. Antenna stabilizers with gyroscopic devices have been used for decades [5]. Beam aberration for transversal satellite movement is corrected [6] and even projectiles can be equipped with antenna arrays to keep the beam direction during rotation [7].

Movable antenna concepts [8], [9] have recently sparked interest and fluid antennas have been proposed as alternative to mechanical antenna movements [10], [11]. Channels can be kept static during receiver movements over distances of several wavelengths with antenna counter-movements that keep the antenna in its original position from the viewpoint of the base station (BS) antenna [12], [13]. Moving antennas can also be used to *maximize* the channel [14], [15], [16]. This work aims to keep channels static by using with-movements at the BS, instead of counter-movements at the mobile device [12], [13].

II. Considerations

Movement at the BS is preferable to mobile devices for several reasons. BSs are usually larger than user equipment (UE). Phones only allow for movements from centimeter to decimeter. Cars now have antenna modules in the decimeter region [17], with some prototypes that utilize the whole car roof [18]. Base station antennas can perform movements within a few meters. There is also a number disparity. Many moving UEs are connected to one BS and compensation methods that only need to be implemented at few BSs are preferable to compensating movement at every UE. Lastly, there is also a cost disparity. More costly methods can be implemented in BSs than in consumer electronics. Fig. 1 shows applications in railway and urban environments.

Consider the sketches in Fig. 2. An antenna moves away from its position along a trajectory T, while it communicates

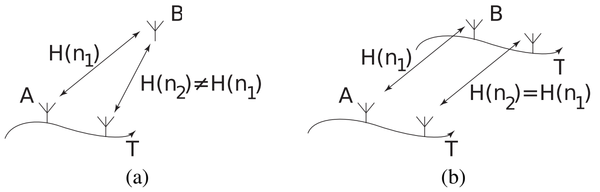


Fig. 2. Antenna A (a UE) moves along a trajectory T while it communicates with BS antenna B through a communication channel H.
a) The BS antenna B remains in a fixed position. The movement changes the channel H.
b) Antenna B moves with A along T. This keeps the channel static as the distance between the antennas and their orientation towards each other never changes.

with a second antenna B through a wireless communication channel H. This movement will in general change the channel, see Fig. 2a. In empty space, the unmoved antenna could partner with the moved antenna and simultaneously move along T to keep the orientation and distance between them. This would subsequently keep the path-loss and phase shift of the channel static, see Fig. 2b. Further objects can be added to the empty space. First, the space can be filled with homogeneous material. Isotropic material assumptions are not required as the direction of arrival stays the same. Second, objects that move along T do not change the channel, as long as the objects themselves or their relevant properties do not change. Radiation patterns do not need to be considered, because the antennas (or their beams for beamforming) are always oriented towards each other at the same angle. Note, that the previously proposed scheme in [12] keeps channels towards antennas at arbitrary positions static, but that this is not the case here. Only the channel between two specific antennas is kept static. A third antenna can keep its communication channels towards antennas A and B static by also moving along T.

However, while the scheme is simple, to the best of the author's knowledge, such a technique that keeps mobile communication channels static on a physical basis with with-movements has not yet been investigated experimentally. Consequently, quantitative performance assessments and channel models are not available. Proof-of-concept experiments are developed and performed in the next section, to provide a baseline quantitative performance analysis and propose mathematical models for wireless communication channels that are kept static by with-movements of the partner antenna.

III. Experiment

The feasibility of channel static partner antennas is experimentally demonstrated with the Vienna MIMO Testbed [19] in an electromagnetically shielded and absorber-lined enclosure. For this proof-of-concept, the trajectory T is limited to linear movement. The trajectories T are realized mechanically with two high-precision computerized numerically controlled (CNC) linear movement units with a positioning accuracy of $0.02\,\mathrm{mm}$ $(0.00016\,\lambda)$, as is sketched in Fig. 3. Both antennas are quarter-wavelength wire monopole antennas for $2.45\,\mathrm{GHz}$. They are placed on circular aluminum ground planes with a diameter of $18\,\mathrm{cm}$ that are elevated from the movement units by $51\,\mathrm{cm}$ high posts. The antennas are connected to a vector network analyzer (VNA) outside the chamber with coaxial cables and feedthroughs. The VNA is trough, open, short and match (TOSM) calibrated up to the antenna ports. The VNA measurements take some milliseconds, but antenna movement during a measurement is undesirable. To prevent movement influences during a VNA sweep, the antennas move to new positions where they are idle for $0.2\,\mathrm{s}$ to dissipate vibrations, then the VNA measurements are recorded and the antennas move to the next position and so on. Consequently, Doppler shift [20] compensation is not measured and evaluated. The movements and VNA measurements are automated with a Matlab script running on a laptop computer.

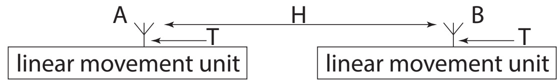


Fig. 3. For the experiment the two antennas are moved by CNC units. Antenna A moves along trajectory T and antenna B simultaneously moves along T to keep the channel static.

Three measurements were performed. First, antenna A moved away from antenna B and the movement remained uncompensated (Fig. 4a). Second, B simultaneously moved with A to keep the channel static (Fig. 4b). Third, both antennas remained still. The data from the third measurement gives a reference channel without movement in the same environment and it provides an upper performance bound for compensation techniques.

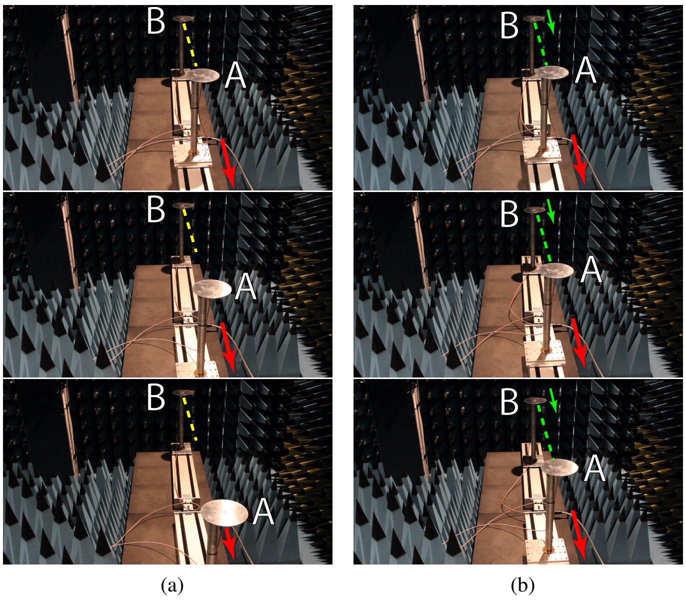
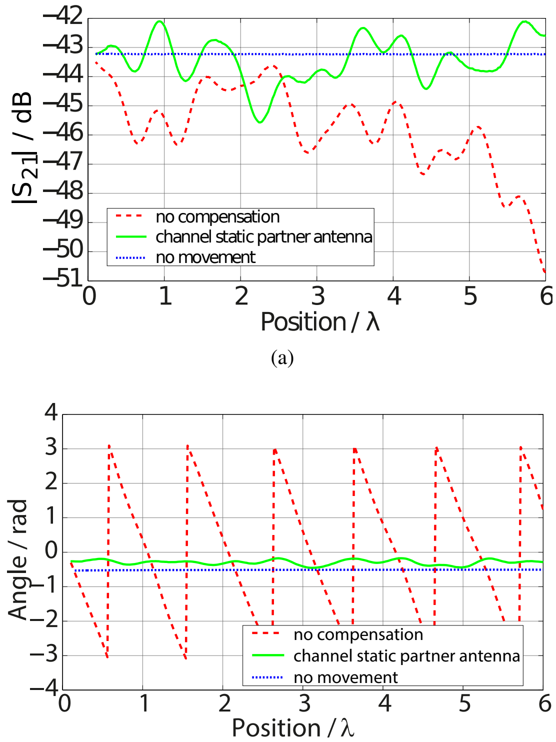


Fig. 4. Top to bottom: During the experiment in the anechoic chamber, antenna A moves towards the front.
a) The wireless communication channel between A and B changes as a result of A's movement.
b) Antenna B keeps the channel static by moving simultaneously with A along the same trajectory T.

IV. Results

The measured S-parameters are shown in Fig. 5 and the statistical analysis is given in Table I. The results without compensation and with the channel static partner antenna are plotted as a function of the distance that antenna A moved from its initial position in wavelengths λ. The results without antenna movement are plotted for a similar time period as the other measurements took to provide a comparison. Without compensation, the the channel's phase shift keeps increasing with distance, but it is wrapped in the plot at 2π for convenient viewing.



(b)

Fig. 5. Measured results with the partner antenna with-movements
a) absolute value and
b) phase. The phase is wrapped at 2π. All images CC-BY 4.0: Gerald Artner

The anechoic environment causes only small variations of path-loss over position (Fig. 5a). Without compensation, the free-space path loss increases with the distance between A and B. The influence of antenna movement on the channel loss is quite low compared to practical environments, but it still reaches 7 dB without compensation. The with-movements reduce the path loss variations to 4.5 dB. The with-movements have the largest influence on the phase shift (Fig. 5b). Without compensation, the phase shift increases proportionally by 2π for each λ increase in distance between the antennas. With with-movements the phase no longer increases with the moved distance and only varies between 0.3 rad ($17°$) peek-to-peek and a variance of $0.0049\,\text{rad}^{-2}$. Overall, the partner antenna keeps the mobile channel static within practical limits.

The remaining changes are likely the result of waves reflecting off metal parts such as the linear movement units and cables that were present during measurements and not covered by absorbers. Inside the anechoic chamber, the channel is kept static within the same order of magnitude as with counter-movements [12]. The counter-movements in [12] show a bit better performance for keeping the path-loss static and the with-movements for the phase, but performance in the anechoic chamber is close and can be considered equal for practical purposes. The results provide a baseline performance for idealized scenarios and what variation can be expected for measurements in more complex scenarios.

TABLE I
Measured mean μ, maximum (peak-to-peak) and variances σ^2 of channel changes.

absolute value	μ / dB	max / dB	σ^2 / dB^2
regular (wrapped 2π)	-45.8	7.22	2.1634
regular (not wrapped)	-"-	-"-	-"-
channel static partner antenna	-43.4	3.47	0.5711
no movement	-43.2	0.04	$4.8166 \cdot 10^{-5}$
channel static antenna [12]	-43.6	2.45	0.4236
phase	μ / rad	max / rad	σ^2 / rad^2
regular (wrapped 2π)	-0.066	6.220	3.41
regular (not wrapped)	-18.449	36.172	109.06
channel static partner antenna	-0.293	0.278	0.0049
no movement	-0.504	0.040	$6.12 \cdot 10^{-5}$
channel static antenna [12]	2.83	0.293	0.0066

V. Channel Model for Channel Static Partner Antennas

In this section, simple channel models are proposed for antennas that perform with-movements to keep their wireless communication channel towards moving antennas static. The models follow those for counter-movements in [12], as the results in Fig. 5 and Table I show similar behavior. The results show that the method keeps the channel static that is present at a given position or time. As the simplest models

$$H(n) = H(n_0) \tag{1}$$

and

$$H(t) = H(t_0) \tag{2}$$

are considered, where Eqs. 1 and 2 are the spatial and temporal formulations, respectively. $H(n)$ and $H(t)$ are the channels at position n and at time t, respectively, and $H(n_0)$ and $H(t_0)$ are the channels at position n_0 and time t_0, from which the channels are kept static. The initial channels $H(n_0)$ and $H(t_0)$ are not determined within the model. They can be obtained from other channel models or simulations, drawn from distributions or estimated from physical channels.

Based on the measurement results, the channel can be modelled as

$$H(n) = H(n_0) + Z(n), \tag{3}$$

where $H(n_0)$ is the channel at the initial position n_0 of the moved first antenna A at which the partner antenna B starts to perform the with-movements. $H(n_0)$ becomes the mean of the channel, as is the case in Fig. 5. It is kept until the second antenna no longer performs with-movements, or starts a new with-movement from a new position that results in a new initial channel $H(n_0)$. Residual changes are modelled by the zero-mean random variable Z, which is drawn for each n, but keeps its variance during a static interval. The model works for path-loss and phase, for example with $\sigma^2_{\text{amp}} = 0.5711\,\text{dB}^{-2}$ and $\sigma^2_{\text{phase}} = 0.0049\,\text{rad}^{-2}$ after Table I. In case antenna B can not perform with-movements indefinitely and chooses to repeat the process with a new channel, then Eq. 3 results in a channel model that is stationary within an interval, analogous to [12]. Specialized models for different scenarios and environments have to be determined in future work.

VI. Conclusion

This work demonstrates that mobile communication channels can be kept static on a physical basis through a with-movement at the remote antenna. Small devices such as smart phones, where it is not possible to perform counter-movements over long distances [12] due to size limitations, can offload the movement compensation to the larger base-station partner-antenna. The experiment in the anechoic chamber provides an idealized baseline for favorable scenarios. The measured values only contain minor scattering and the influences of the antennas being moved relative to the metal movement units. The results are promising. Free-space path loss and phase shift no longer increase proportionally with the distance between the antennas and are instead transformed to residual changes around a mean with a variance of $0.57\,\text{dB}^{-2}$ and $0.0049\,\text{rad}^{-2}$, respectively. The measured performance in the anechoic chamber is similar to channel static UE antennas that perform counter-movements [12].

This proof-of-concept motivates further experimental research. The achievable performance in different scenarios and environments needs to be evaluated, and design consideration for development of moving BS antennas need to be gathered. Early investigations likely want to abstract position and movement estimation (determination of UE trajectory T). The proposed experimental setup solves this issue by simultaneously positioning both antennas with high precision. The mechanical movement units can later be used to reproducibly introduce position and movement uncertainty into experiments. Practical partner antenna needs two key features: A way to obtain T and a mechanism to move along T. Both problems require inventive solutions.

VII. Conflicts of Interest

Technische Universität Wien filed a patent application [21].

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