White Paper

MIMO Systems in Linear Cells by virtue of Radiating Cables

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November 2016

About the Author

NIMA JAMALY holds five graduate and post graduate degrees in different fields of electrical engineering. He received a PhD degree in Advanced Wireless Communication Systems from Chalmers University of Technology, Sweden, in 2013. Dr. Jamaly is most known for inventing the first ultra-wideband in-ground MIMO antennas for small-cell applications worldwide. His research area is broad and includes small multiport antenna design, wideband base station antenna design, mm wave array antenna design, beam-forming, signal processing, reverberation chambers, radiating cables, characterisation of multipath environments etc. Dr. Jamaly has several patents which are licensed to different companies and has won a number of awards and grants during his professional career.

1. A Brief Introduction to MIMO Systems

Wireless communication is based on propagation of electromagnetic waves, creating a wireless link between the transmitter and the receiver. Initially, time and frequency bandwidth were the two resources used by the mobile communication systems to send data to different users. In these systems the best scenario occurred when both receiver and transmitter antennas had direct line-of-sight (LOS) towards each other.

Nevertheless, further investigation on wireless links revealed that in most cases, a LOS scenario in which both transmitter and receiver see each other eye-to-eye is not the dominant case. Instead, the LOS links are normally blocked in different ways, for instance, by walls, users, cars, buses etc. Under this condition, the electromagnetic waves arrive at the users' positions through reflection, refraction, diffractions, transmission mechanisms, or through multiple bouncing between different scatterers surrounding the receiver or transmitters. This scenario is known as *multipath*.

In a multipath scenario, dependent on the spatial position of the receiver, electromagnetic waves travel through different independent paths (i.e., wireless links). This indicates that, in general, certain *spatial signatures* are associated with receivers located at sufficiently separated positions. Recently, scientists have realised that they can use these spatial signatures to distinguish between different users. This simply means, in addition to the *frequency* and *time*, there is one more resource to be used to increase the data throughput or to enhance the reliability of the system; that is, *space*. In other words, we could use the same frequency bandwidth and simultaneously send independent data to different users at different locations near each other.

To accomplish this, in modern communication systems scientists use multiple antennas at the transmitter and the receiver sides. These systems are referred to as multiple input-multiple output (MIMO) systems. In contrast to MIMO systems, the classic communication systems with single port antennas at both the transmit and the receive sides is referred to as single input-single output (SISO) systems.

The main advantage of the MIMO communication systems[1] compared to the SISO ones is the enhanced *spectral efficiency*. Compared to SISO systems, MIMO systems provide higher data rates over the same frequency bandwidth. However, they require certain condition to realise their maximum performance. For instance, the presence of multipath environments can –to a great extent– help to separate out different signals of similar frequency band which are received simultaneously. In these circumstances, MIMO systems generally work best.

[1] MIMO systems have several radio frequency (RF) chains. Note that having more RF chains increases the cost and complexity of the system.

2. Wireless Communications in Linear Cells

Wireless engineers are required to provide electromagnetic coverage to all users in variety of scenarios including indoors, outdoors, dense city downtowns, urban environments, rural environments etc. There are also some applications wherein engineers are dealing with cells which are long in one dimension and confined in the other dimension. These wireless cells are mostly known as *linear cells* [1]. An examples of such cells are aisles, tunnels, subway paths, and along the railroads.

Application of regular base station antennas installed on posts for linear cells is limited in two ways. Firstly, at mobile communication frequencies the free space pathloss is relatively high. Secondly and particularly for free space linear cells, the radiation will not be confined along the desired path. This is mostly the case where a dedicated wireless communication infrastructure is going to be assigned to a linear cell. To overcome the foregoing issues, engineers recommend using radiating cables (RCs).[2] These cables are installed parallel to the linear cells and provide coverage along them with longitudinal loss which is considerably less than the free space pathloss. Meanwhile, the amount of radiation in the undesired direction is also quite limited, exposed to a pathloss largely exceeding the free space pathloss.[3]

The current white paper addresses the application of RCs in both SISO and MIMO wireless communication systems. Through actual measurements, we demonstrate the advantages of using RCs in linear cell applications. In the following section, we start with a description of the measurement setup.

3. Measurement Campaign

A measurement campaign was set up in Eupen, Belgium, wherein an actual LTE system testbed has been used to measure the channel between the base station and the user equipment. The base station was connected to one or two 60 m long RCs. On the other end, a mobile trolley with two reference receive antennas[4] with different specified polarisations were used. The separation between the co-polarised receive antennas was 25 cm, which is a typical length used in MIMO Train Antennas available in the market. Fig. 1 provides a view of the described scenario which is mostly known as free space method. Free space method is associated with a free space measurement configuration with an RC, wherein receive antennas are reference dipoles at the same height as RCs i.e., 1.5-2.0 m from the ground, and 2 m distance from the cable. All channel information was thus recorded by a laptop which was directly on the measurement trolley used for this purpose.

[2] Radiating cables are also known as leaky feeder cables (LFCs).

[3] Typically, the users in linear cells are in the near-field radiation of the long RCs. Some of these near fields vanish when one moves away from the cable leading to an increased pathloss in the unwanted direction.

[4] The receive antennas were wideband dipoles by Kathrein (product no. 80010847)

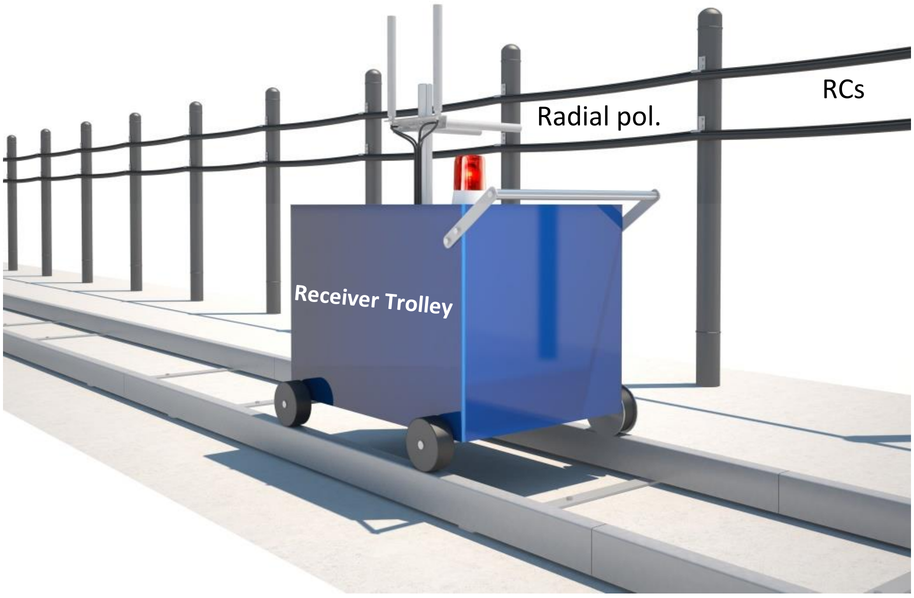

Figure 1: Free space measurement set up with RCs and measurement trolley.

The input power to the RCs was 10 dBm per subcarrier (38dBm composite input power) with a 10 MHz bandwidth at a frequency 1790 MHz. The RCs' slots were oriented towards the trolley, i.e., 90° from the sky. The RCs were both Eupen RMC-158 Broadband cable. To achieve the throughputs, a reliable empirical model was used. This model is associated with the extended pedestrian A model (EPA 5) with transmit mode 3 (TM3) and 64-QAM modulation scheme [5]. In this model, the number of cell-specific reference signals was two (CRS 2) and the channel format indicator was set to one (CFI 1). The maximum achievable throughput was around 37 Mbps for the SISO (1 × 1) mode of operation and 74 Mbps for 2 × 2 MIMO mode.

Throughputs for longer lengths of the RCs were calculated by incorporating the measured RC's longitudinal loss represented through attenuation of the input power. Further details of the presented measurements and channel information have been published in [2].

4. Measurement Results

4.1 SISO–RMC-158 Broadband Cable

In this measurement, signals were fed into one end of the RCs and 50 Ω termination was used on the other end of the RCs. The typical noise plus interference level at 10 MHz bandwidth was around -105 dBm.

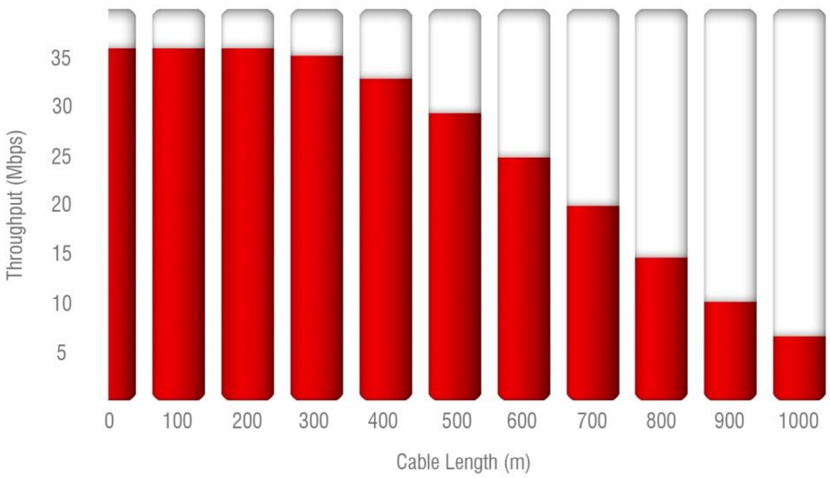

Figure 2: LTE throughput operating in SISO mode versus distance (Eupen RMC-158-HLFR “A”-Series Broadband cable) at 1790 MHz for 10 MHz bandwidth and 10 dBm per subcarrier input power.

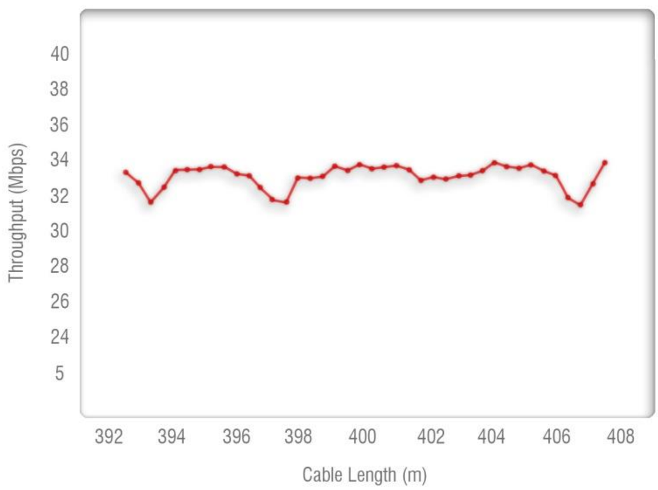

Figure 3: Throughput at around 400 m distance averaged over 35 cm cable length (f = 1790 MHz, 10 MHz bandwidth, and 10 dBm per subcarrier input power).

Radial polarisation was used for these measurements (see Fig. 1). The result of the data throughput is presented in Fig. 2. In this figure, each bar shows the throughput averaged over 15 m length around the given distance.

From Fig. 2. it is evident that at shorter lengths, due to the high signal to noise ratio, the maximum throughput is almost fully realised. As soon as the longitudinal loss becomes significant, due to the longer propagating distance from the feed point, the throughput is negatively impacted.

To better visualise the throughput variation and the impact of averaging in more detail, in Fig. 3 we show the variation of throughput at around 400 m. Here the throughput results were averaged over a 35 cm length. Based on this figure, the throughput has only slight variation along the path, which is in general an advantage especially when the user moves at higher velocities.

4.2 MIMO–Eupen RMC-158-HLFR "A"-Series Broadband Cable

No doubt, a more interesting and novel application of RCs is in MIMO systems. MIMO systems are highly preferred to SISO systems for the higher throughput they provide over the same frequency bandwidth. A common belief among engineers is that for a MIMO system to work effectively, we require a multipath environment, like those in the buildings, tunnels etc.

Nevertheless, it has already been demonstrated that there is not such a strict requirement for RCs to provide a spectrally efficient MIMO system [3]-[4]. In this frame, we used the same scenario as for the former SISO case with two identical RCs whose slot orientations were similar.

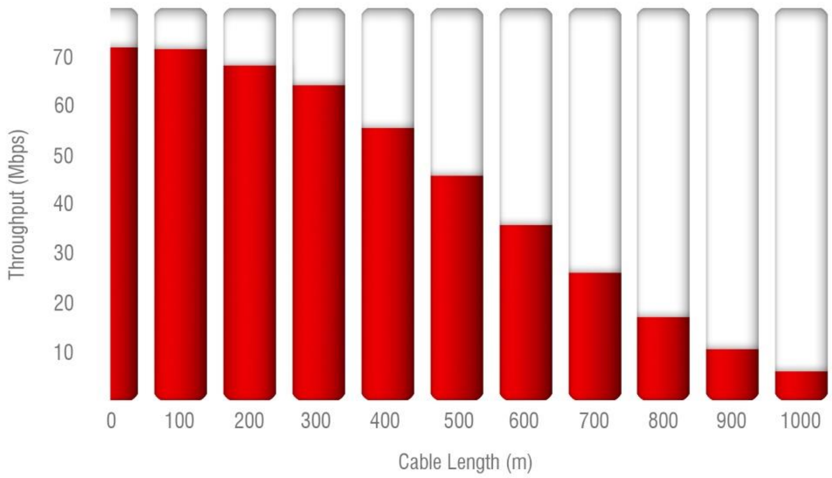

Figure 4: LTE MIMO throughput (RMC-158 Broadband) at 1790 MHz for 10 MHz bandwidth and 10 dBm per subcarrier input power.

The RCs were fed from one end and terminated at the other end. The separation between the co-polarised receive antennas was 25 cm. The results of the corresponding throughputs are presented in Fig. 4. In contrast to SISO configuration in Fig. 2, MIMO setup provides significantly higher throughput over the same bandwidth. These results prove the application of RCs even in free space scenarios for achieving a throughput close to an ideal MIMO system.

4.3 MIMO with a Single Cable Deployment

A further fascinating and exclusive feature of RCs is to yield a 2 × 2 MIMO system using a single RC. For this purpose, the two independent signals are fed into opposite ends of an RC[5] [1]-[2].
A measurement setup was configured wherein two LTE signals were injected into the 60 m long RC at its both ends. On the user equipment side, the same trolley as before was used (see Fig. 5). The slot orientation of the RC was again at 90° and the input power to the RC was similarly 10 dBm. Based on the measured RC longitudinal loss, we used the attenuation corresponding to different RC lengths and plotted the throughputs for these different RC lengths in Fig 6a, b and c. [5]

Recall that, as the wave propagates within the RC, the longitudinal loss causes some imbalance in the received powers particularly close to either end of the RC. In contrast, as the user moves towards the middle of the RC, the power imbalance between the two received signals reduces. Thus, one expects that the throughput varies in some way as the user moves alongside the RC. Surprisingly, as it is clear from the results in Fig. 6, for these lengths, a user experiences a constant average throughput throughout the path. Indeed, these results interestingly demonstrate that the power imbalance at RC's both ends and the reduced overall receive powers at RC's midpoint have identical impacts on the throughput reduction. [5]

Nevertheless, dependent on the RC's length, the total throughput for longer cables is less. Particularly, as the length of the cable exceeds certain amount, the excessive power imbalance close to either end of the RC causes the system to simply turn into a SISO system. This occurs regardless of the level of receive SNRs. Therefore, the throughput reduces near both ends of the RC. Fig. 7 shows the throughput versus distance for such a scenario (e.g., cable length is 700 m).

A brief glance over the results in Fig. 4 and Fig. 6 clearly reveals that deploying a single cable yields better MIMO throughput. This enhancement is best attributed to the improved MIMO channel condition as illustrated in [2, Fig. 8], and is exclusive to a certain type of RCs.

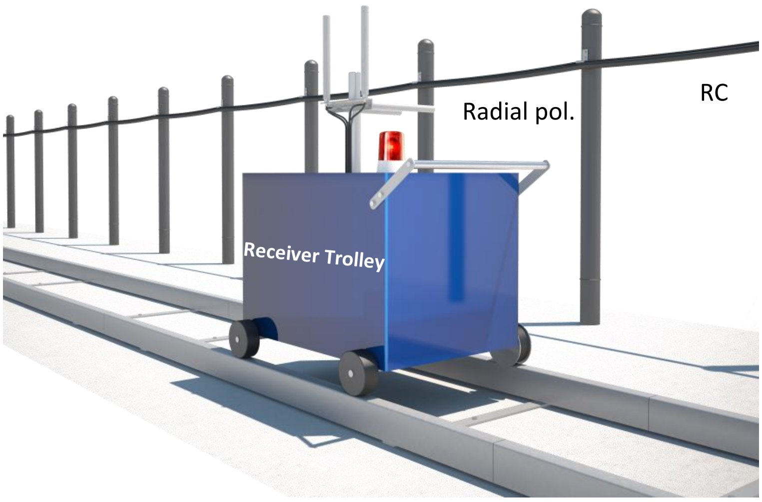

Figure 5: Free space measurement set up with single RC and measurement trolley.

[5] Eupen EUCARAY® RMC-158-HLFR "A"-Series Broadband Cable.

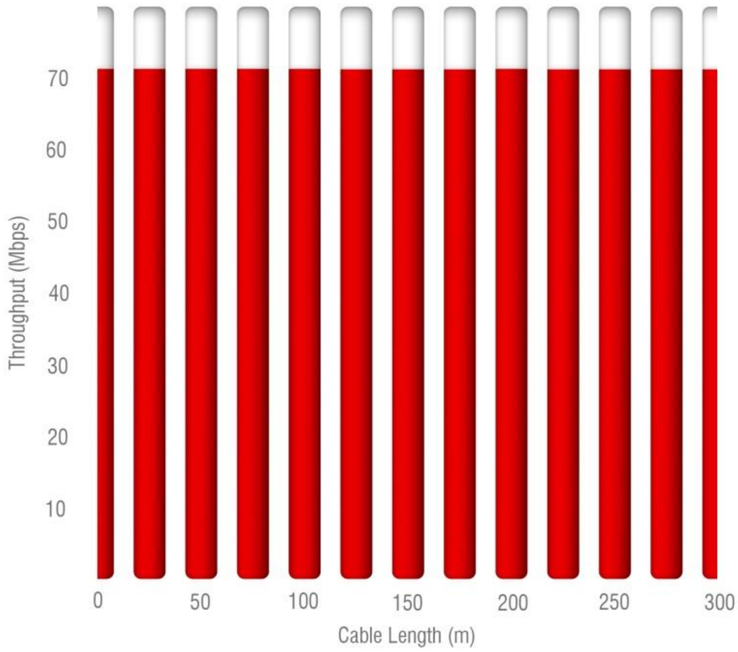

Figure 6: (a) RC length 300 m

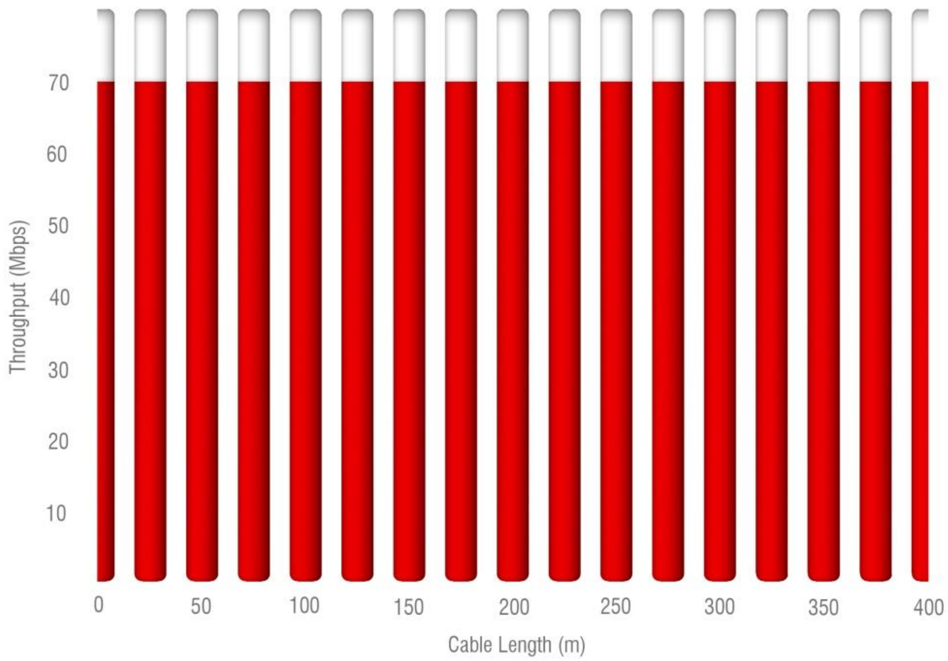

Figure 6: (b) RC length 400 m

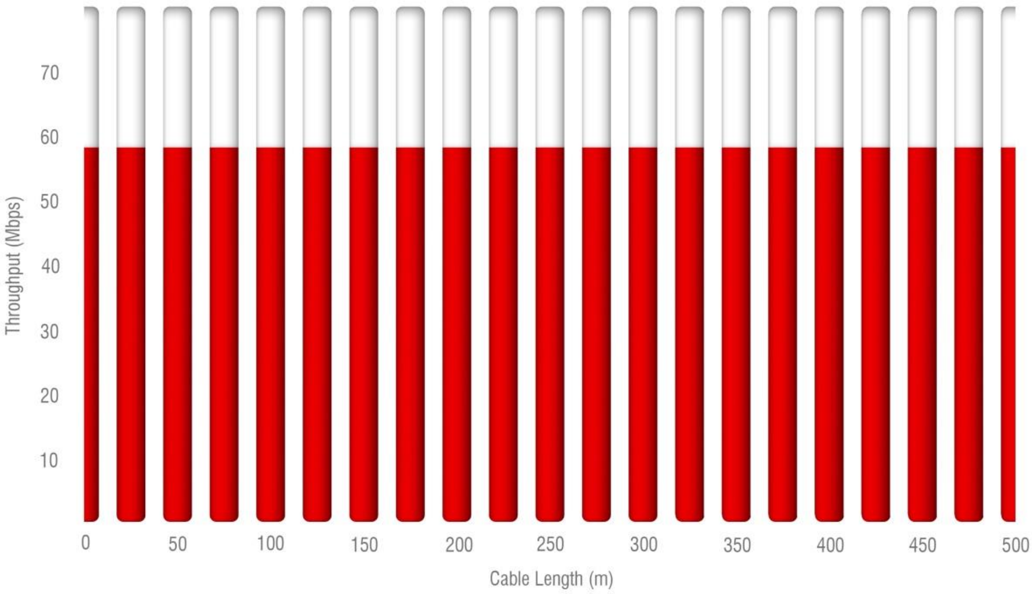

Figure 6: (c) RC length 500 m

Figure 6: Throughput versus lengths of an RC which is fed in its both ends by two independent signals. This scenario belongs to radial polarisation and is associated with [2, Fig. 8].

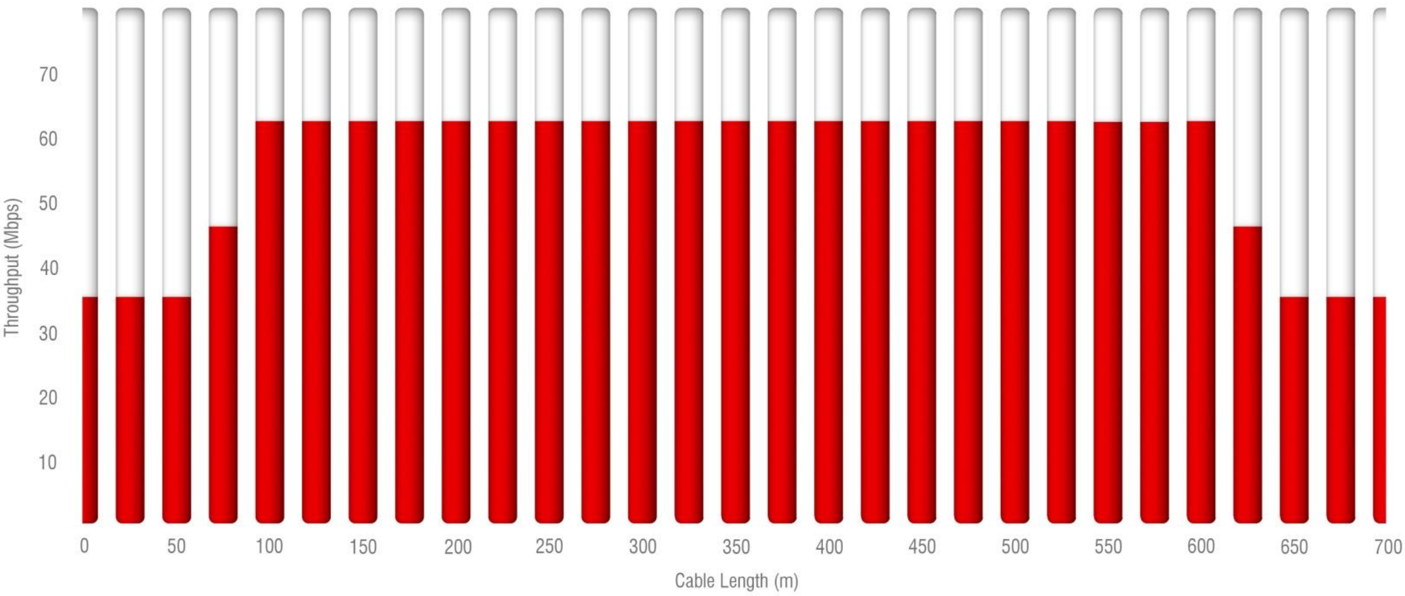

Figure 7: Throughput for a 700 m long RC which is fed in its both ends with two independent signals. All other associated parameters are similar to those of Fig. 4.

5. Conclusion

We have demonstrated that RCs are valuable options in linear cell wireless communication applications and provide sufficient throughput in SISO systems at least for lengths up to 500m.[6] For SISO application, the longitudinal loss plays an important role.

Furthermore, we have shown that a MIMO system works well with two co-polarised RCs in free space scenario. In [2] we discussed that RC itself can create a multipath-like scenario along it which supports achieving fine MIMO throughput.

In addition, feeding a single RC from its both ends showed significant improvement with respect to the case wherein two RCs where fed at one end. This condition is mostly valid for cable lengths less than 500 m. Surprisingly, we also observed that in the latter case, the average throughput all along the RC is constant. This is also a valuable feature. Recall that in the frame of this paper we restricted ourselves to radial polarisation. Nevertheless, we emphasise that as long as an RC provides similar coupling losses and identical distributions of the receive signals for different polarisations along it, the resultant throughput will be independent of the receive antennas' polarisations.

Figure 8: Eupen EUCARAY® RMC 158-HLFR "A"-Series

[6] This number is valid for the given cable (i.e., Eupen EUCARAY® RMC-158-HLFR "A"-Series Broadband) with radial polarisation and for 10 dBm per subcarrier input power in free space method (see Fig. 8).

6. Further Points and Discussion

- As long as the coupling between the two cables does not violate the required isolation between the ports[7], our further measurements also show that tying the two RCs together does not impact the MIMO throughput. This had also already been observed in indoor scenarios [7]. Therefore, having certain amount of separation between the two RCs is not strictly required to yield MIMO throughput.

- Recall that all the presented results are based on free space method, wherein there is no scatterer around the RCs. The presented results demonstrate that a MIMO system using RCs works effectively in LOS scenarios. In contrast, the presence of RC within tunnels, aisles etc. with a number of surrounding scatterers helps to further improve the system performance. Therefore, our prediction is that, as long as the receive SNRs are similar, better throughputs than those presented in this paper will be obtained when we use RCs in tunnels etc. Particularly, the presence of trains within tunnels with huge metallic surface must increase the richness of the multipath scenario and therefore enhance the throughput even more [8].

- We showed that feeding a single RC from its both ends yields better MIMO performance. However, we acknowledge that this enhancement will be exclusively achieved by RCs whose main direction of radiation is close to their axes. RCs whose main direction of radiation is normal to their axes are most likely useless for this type of deployment.[8]

- It is known that users moving alongside RCs experience a multipath-like environment. Dependent on frequency, polarisation, distance from the RC etc. users also experience different fading distributions. To combat fading, one can use a single RC and increase the number of receive antennas. The signal at the ports of these antennas can be combined by any known diversity scheme rendering a receive signal of better distribution and thus improved throughput [9].

- Bear in mind that if RCs in tunnels are going to be used to support antennas on the railway carriages, engineers might use certain polarisation or slot orientation to improve the system performance. However, if the RCs are used to directly support user equipments within the railway carriages etc., the scenario will be more complex. The reason is, the polarisation of the user equipment can be quite arbitrary. In this case, probably the safest option is to use RCs with similar polarisation but reduced coupling loss to make sure the average receive SNR is sufficiently high. Our former works demonstrated that regardless of the transmit mechanism, there is a rich multipath environment within the wagons [10]. In this case, engineers are recommended to focus more on enhanced receive power than the polarisation and channel distribution.

[7] Based on 3GPP's requirements [6], there must be around 30 dB isolation between the two ports of a MIMO basestation.
[8] Eupen EUCARAY® RMC Radiating Cables are especially designed with their main direction of radiation close to their axis.

References

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