



Overcoming the Challenges of 4G LTE and MIMO for In-Tunnel Wireless Connectivity

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➔ Abstract

As mobile wireless continues to make the transition to data and video-dominated broadband, unprecedented demands are being placed on operator networks. Thus, 4G LTE networks are deployed worldwide – mainly in macro environments – to support this increasing data throughput demand for mobile users everywhere. However, specifically for in-tunnel applications, deployment of 4G networks has just started.

The purpose of this white paper is to review the design challenges for in-tunnel LTE applications and to analyze the key performance indicators. The document summarizes the results of a comprehensive measurement campaign focusing on in-tunnel LTE performance based on RFS RADIAFLEX® radiating cables.

Furthermore, a number of test cases have been executed to investigate the applicability of MIMO technology in tunnel environments and to identify its individual requirements. The white paper gives insight to the individual test configurations as well as the results which have been achieved.

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➔ Test Environment

A 'real life' LTE test set-up has been installed in a test tunnel (Figure 1) located in Hanover, Germany.

The test setup consists of a 4G base band unit (BBU) controlled by a core network emulator. The BBU is connected to a MIMO-capable radio remote head (RRH) which was used to provide the RF signal(s) for the in-tunnel coverage via one radiating cable (SISO) or via two radiating cables (2x2 MIMO).

The Tx/Rx ports of the RRH are connected via feeder cables and variable attenuators to the radiating cables which are mounted on the wall of the tunnel at a height of two meters. For MIMO test cases a spacing of 30cm between the radiating cables has been considered.

A mobile (UE) has been installed at a height of 2m on a trolley which was moved 2m away from and along the radiating cable. Thus, the test set-up is in accordance with IEC 61196-4 standards.

The UE is controlled by a PC via USB interface which reads all relevant LTE signal KPI's (e.g. RSSI, modulation coding scheme, etc.) and measures the downlink data throughput via file transfer from the ftp server hosted by the core network emulator.



Figure 1 Test tunnel

The tests have been executed in the 850MHz LTE band utilizing a carrier bandwidth of 10MHz. Maximum achievable throughput limited by eNB software and hardware was around 28Mbit/s for SISO and 48Mbit/s for MIMO based on a modulation coding scheme of 64QAM.

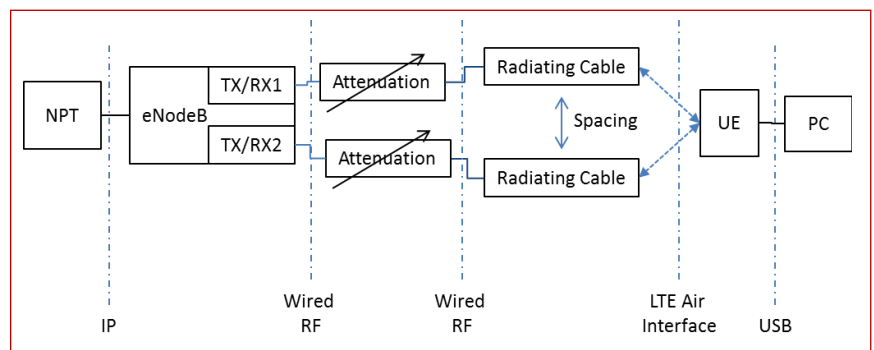


Figure 2 Test configuration

The length of the radiating cable section in the tunnel was 60m. Simulation of longer cable length is done by attenuating the RF feeding power into the radiating cables. The test configuration is illustrated in Figure 2.

The following radiating cables have been subject to the tests:

- SISO: RLKU158-50JFNAH
- MIMO: combination of 2x RLKU158-50JFNAH as well as a combination of RLKU158-50JFNAH and RAYS158-50JFNA



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➔ Test Results

SISO – Single RLKU158-50JFNAH

A number of SISO test cases have been analyzed. Specific focus was on the variation of feeding power into the radiating cable to research the dependency between possible data throughput and length of the radiating cable section.

For a feeding power level of 10dBm, the maximum possible data throughput of roughly 28Mbit/s provided by the eNB has been achieved up to an equivalent cable length of 20dB. This insertion loss of 20dB is equivalent to approximately 870m, taking into account the longitudinal loss of the radiating cable at 850MHz.

Afterwards, the signal-to-noise ratio degrades with the decreasing RF signal power level and is no longer sufficient to support the highest 64QAM modulation coding scheme which automatically results in a reduced end-to-end data throughput.

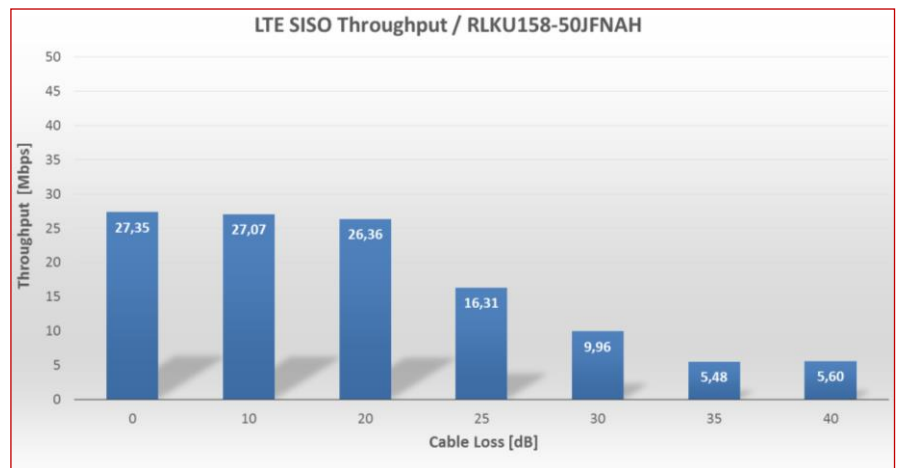


Figure 3 SISO throughput results for RLKU158-50JFNAH

Considering the longitudinal loss of the RLKU158-50JFNAH radiating cable at 850MHz, the results can be generalized to derive conclusions about the performance, e.g. in the 2.6GHz LTE frequency band. The longitudinal loss of the radiating cable increases from 2.3dB/100m to 5.8dB/100m and the coupling loss of the cable improves by 6dB (95% average). The effective useful length of the radiating cable supporting the highest modulation coding is approximately 450m.

About MIMO – General Thoughts

Another key aspect of the study was to investigate the MIMO performance in a tunnel environment based on two radiating cables as transmit / receive antennas.

Figure 4 shows a principle configuration of a MIMO system including a BTS / Node B and a Mobile / UE. In this case the Tx and Rx units have two individual Tx-Rx paths, radio channels 1 and 2, to distribute two signals in parallel at the same time in the same spectrum. The distribution can be direct or over multi-paths due to reflections. These multi-paths enable un-wanted cross-couplings between the radio channels.

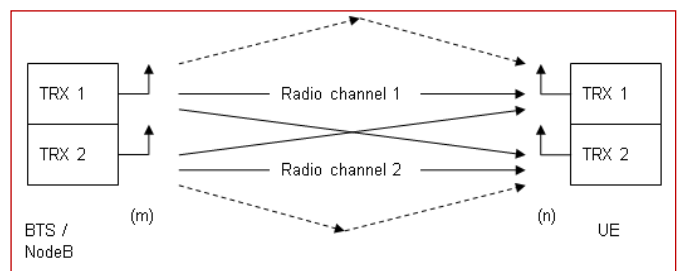


Figure 4 2x2 MIMO configuration



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The number of antenna elements, m at Tx and n at Rx, determine the order of the MIMO system. Figure 4 shows a 2 x 2 MIMO system.

Typically, MIMO requires a multipath environment between transmit and receive antennas in combination with a high signal-to-noise ratio. The functionality of MIMO requires stochastically independent signals in order to identify the cross-coupled signals. The condition is fulfilled in terms of a cable spacing of 30cm ($> \lambda/4$) and a highly reflective tunnel environment providing a high grade of multipath.

On the other hand, the individual propagation paths between receive and transmit antennas has to be ideally uncorrelated. This requirement is the challenge for in-tunnel MIMO scenarios as usually the transmit antennas, or more precisely two radiating cables, are typically installed very close to each other with a line-of-sight condition to the receive antennas which imposes the propagation paths to be correlated.

MIMO Based on Identical Types of Radiating Cables

The first test case focusing on MIMO performance is based on two identical types of radiating cables which have been installed at the tunnel wall separated by 30cm using two parallel runs of RLKU158-50JFNA.

Figure 5 summarizes the throughput results that have been achieved. Generally, the measurements confirm that MIMO is possible increasing the throughput compared to SISO by 57% to 42Mbit/s. With decreasing signal-to-noise ratio, starting between 10 and 20dB equivalent cable loss, high fluctuation of the modulation coding scheme used for the individual propagation paths has been observed.

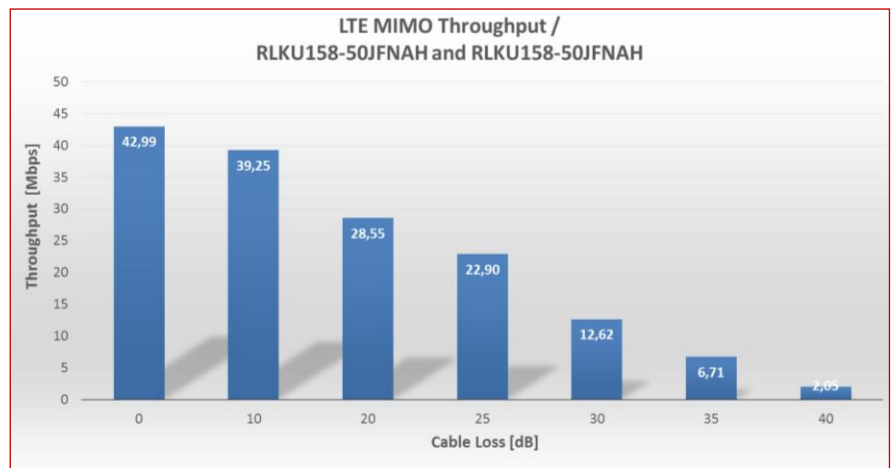


Figure 5 MIMO performance for identical types of radiating cables

For longer equivalent cable runs, MIMO is not used anymore to transfer the data and the throughput results are getting close to the SISO case.

The benefit of MIMO quickly disappears with decreasing power level or longer cable runs. Throughput results are close to the SISO case and only minor advantages due to diversity have been observed.



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MIMO Based on Two Radiating Cables with Different Dominant Polarization

The second MIMO test case focusses on a MIMO scenario where two radiating cables with different main polarizations have been used:

- RLKU158-50JFNAH: dominantly horizontally polarized
- RAYS158-50JFNA: dominantly vertically polarized

Again, the measurement results confirm that MIMO is working properly achieving a throughput of ~48Mbit/s (+68% compared to the SISO case), which is the limit given by the eNode B hardware and software.

A detailed analysis of the measurement data points out that a degradation of signal-to-noise ratio, as for the previous test case, has far less impact on the measured throughput. Even at an equivalent cable loss of 25-30dB MIMO is still operational, but due to the reduced signal-to-noise ratio only with modulation coding schemes that support a lower overall data rate.

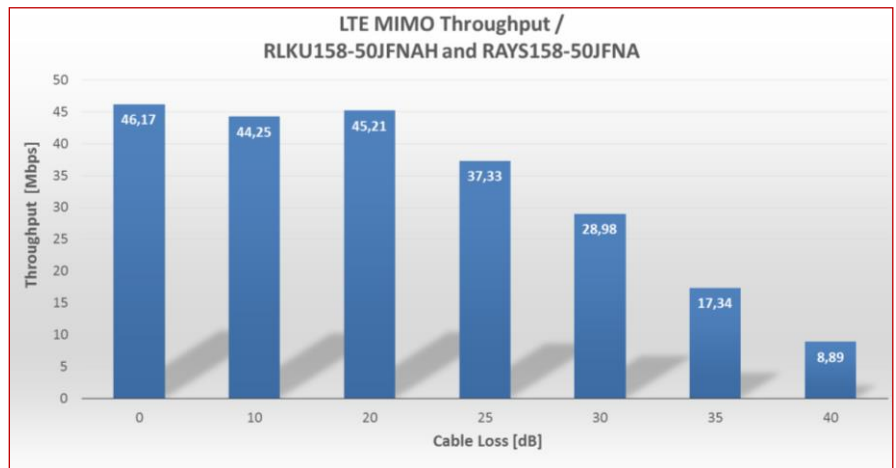


Figure 6 MIMO performance for identical types of radiating cables

This test case demonstrates that using two differently polarized radiating cables increases the effect of de-correlation of the two Tx signals, visible due to higher throughput at high signal-to-noise ratios even at 30dB equivalent cable loss.

➔ Conclusion

Even if LTE, almost often in combination with MIMO technology, has already been deployed for a while in a number of macro networks, the technological constraints and challenges for in-tunnel applications based on radiating cables is quite new. The study clearly demonstrates that MIMO conditions in a tunnel environment can be achieved with two separated radiating cables installed at the tunnel wall. Even if the individual signal paths might be correlated to a certain extent, the highly-reflective environment ensures proper MIMO conditions.

Furthermore, when comparing the above described test cases (see Figure 7), it becomes evident that the differently polarized radiating cables stimulate the in-tunnel MIMO performance similar to a cross-polarized base station antenna deployed in macro sites.



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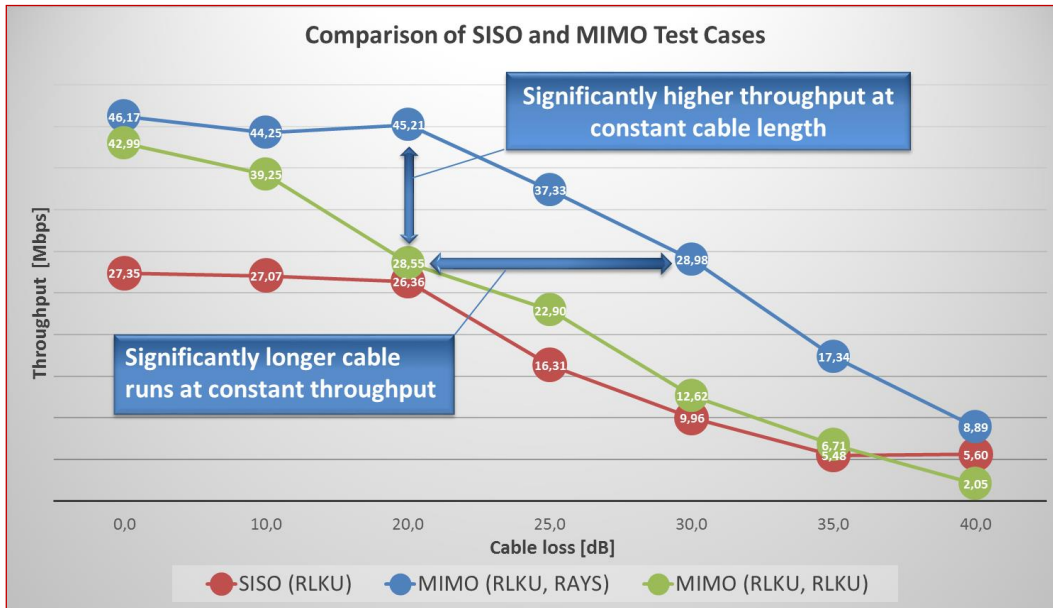


Figure 7 Comparison of SISO and MIMO test cases

The direct comparison of the SISO and of the two MIMO test cases described above reveals the clear advantage of using MIMO in tunnels to provide a higher data throughput based on two radiating cables with different dominant main polarization different from each other. This approach allows for significantly higher data throughput at a constant cable length compared to the other two cases or allows for significantly longer runs of radiating cable at a constant data throughput.



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➔ RFS RADIAFLEX® Radiating Cables

RADIAFLEX® high-performance radiating cables are the world's leading "leaky feeder" cable solution. Designed to provide "contoured" RF indoor coverage, RFS RADIAFLEX® cables provide a scalable and practical means of tailoring RF coverage in even the most challenging of confined spaces.

RADIAFLEX® cables support all major services from 75MHz to 6GHz, making them optimally suited for multi-operator and multi-band applications. Featuring low longitudinal and coupling losses, RADIAFLEX® cables are ideally suited for all kind of applications where highest performance standards have to be met.

RFS is a major player in the tunnel market place for more than 40 years. The long experience in the field of radiating cables is the basis for the wide portfolio of outstanding products which allows customers to select the best suited product for a variety of individual applications.

RLK Product Series

The RLK series is designed for all kind of in-tunnel applications. The specific slot arrangement and geometry allows for mode suppression technology minimizing number of unusable frequency bands. Radiation is quite homogenous with regard to the spatial orientation of the receive antennas. However, the dominant radiation polarization is horizontal.

Worldwide leading edge product is the RLKU158-50JFNAH radiating cable which provides an ultra-broadband useable frequency band of 700 to 2700MHz to the customer applicable to all kind of 2G/3G/4G mobile services in any frequency band.

RAY Product Series

Similar to the RLK series, the RAY type radiating cables are applicable to a broad spectrum of application. They provide a dominant vertical radiation polarization which makes the RAY series an excellent match for all kind of applications where the radiating cable has to serve a vertically polarized train antenna.

The flagship of the RAY product family is the RAYS158-50JFNA which is an ultra-broadband radiating cable supporting all mobile wireless services between 700 and 2700MHz.

