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# Going underground with LTE in Hannover

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**Attempts to offer a 4G LTE mobile network service in tunnels remain in their infancy. However, trials with "leaky feeder" cables in Hannover have shown that it is possible to deliver reliable mobile broadband services underground, as Axel Schroeder, commercial product manager indoor systems at Radio Frequency Systems, explains.**

WITH mobile wireless services making the transition to data and video-dominated broadband in recent years, there is unprecedented demand on operator networks to deliver the level of service required to a high number of people.

4G Long Term Evolution (LTE) networks are currently being rolled out across the world mainly in macro environments to meet this demand for all kinds of mobile users. However, rollout of 4G in-tunnel applications and networks has only just begun.

For railway and metro operators, offering a 4G network connection is becoming more critical to keep up with passenger demands for continuous access to data and mobile services while they are on the move. As a result Radio Frequency Systems (RFS) conducted a comprehensive measurement campaign focusing on in-tunnel LTE performance based on its Radiaflex radiating, or leaky feeder, cables to review the design challenges for in-tunnel LTE applications and to analyse key performance indicators (KPIs).

In addition a number of test cases have been executed to investigate the applicability of multiple-input multiple output (Mimo) technology in tunnel environments and to identify its individual requirements. This article provides insights to the individual test configurations as well as the results which have been achieved from a series of "real life" LTE tests in a test tunnel in Hannover, 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 (Single Input Single Output (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 2m. For Mimo test cases a spacing of 30cm between the radiating cables was considered. A mobile (UE) was 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 the IEC 61196-4 standard.

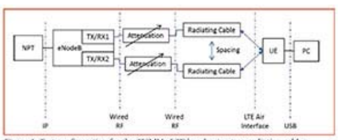


*Figure 1: Test configuration for the 850MHz LTE band using two radiating cables.*

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

The tests were executed in the 850MHz LTE band utilising a carrier bandwidth of 10MHz. The maximum achievable throughput through the eNB software and hardware was around 28mb/s for Siso and 48mb/s for Mimo based on a modulation coding scheme of 64QAM. The length of the radiating cable section in the tunnel was 60m. Simulation of longer cable length is achieved by attenuating the RF feeding power into the radiating cables.

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The test configuration is illustrated in Figure 1 and the following radiating cables have been subject to the tests:

- Siso: RLKU158-50JFNAH (cable 1), and
- Mimo: combination of 2x RLKU158-50JFNAH (cable 2) as well as a combination of RLKU158-50JFNAH and RAYS158-50JFNA (cable 3).

**Test results**

A number of Siso test cases were analysed, with a specific focus on varying the power fed 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 28mb/s provided by the eNB is 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.

Beyond this, the signal-to-noise ratio degrades with 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. Considering the longitudinal loss of the cable 1 radiating cable at 850MHz, the results can be generalised to derive conclusions about performance, including in the 2.6GHz LTE frequency band.

The tests show that 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.

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

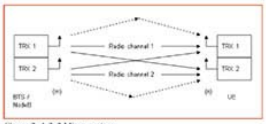


*Figure 2: A 2x2 Mimo system.*

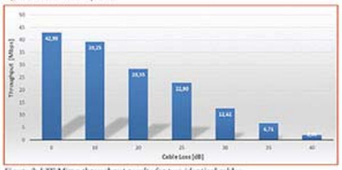


*Figure 3: LTE Mimo throughput results for two identical cables.*

Figure 2 shows a principle configuration of a Mimo system including a BTS/Node B and a 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 multipath due to reflections. These multipaths enable unwanted cross-couplings between the radio channels, with the number of antenna elements, m at Tx and n at Rx, determining the order of the Mimo system.

Figure 2 shows a 2x2 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 (> λ/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 ideally is uncorrelated. This requirement is a real challenge for in-tunnel Mimo scenarios as usually the transmit antennas, or more precisely two radiating cables, are installed very close to each other with a line-of-sight condition with the receive antennas, thus requiring a correlation of the propagation path.

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 and are separated by 30cm using two parallel runs of cable 2.

Figure 3 summarises the throughput results. Generally, the measurements confirm that Mimo is possible by increasing the throughput compared with Siso by 57% to 42mb/s.

With decreasing signal-to-noise ratio, starting between 10 and 20dB equivalent cable loss, it is possible to observe high fluctuation of the modulation coding scheme used for the individual propagation paths. For longer equivalent cable runs, Mimo is no longer used to transfer the data, with the throughput results getting close to the Siso case.

The second Mimo test case focuses on a Mimo scenario that uses two radiating cables with different main polarisations:

- RLKU158-50JFNAH: dominantly horizontally polarised, and
- RAYS158-50JFNA: dominantly vertically polarised.

Again, the measurement results confirm that Mimo is working properly and achieves a throughput of 48mb/s (an improvement of 68% compared with 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 only with modulation coding schemes that support a lower overall data rate due to the reduced signal-to-noise ratio.

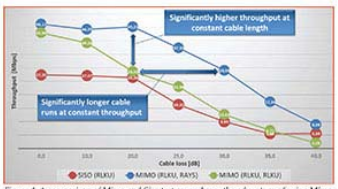


*Figure 4: A comparison of Mimo and Siso test cases shows the advantage of using Mimo.*

Even if LTE, almost always 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 it is possible to achieve Mimo conditions in a tunnel environment by installing two separated radiating cables in 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 4), it becomes evident that the differently polarised radiating cables stimulate an in-tunnel Mimo performance similar to a cross-polarised base station antenna deployed in macro sites.

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