M2M Cellular Antennas: SISO v. MIMO

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COMMUNICATIONS

Introduction

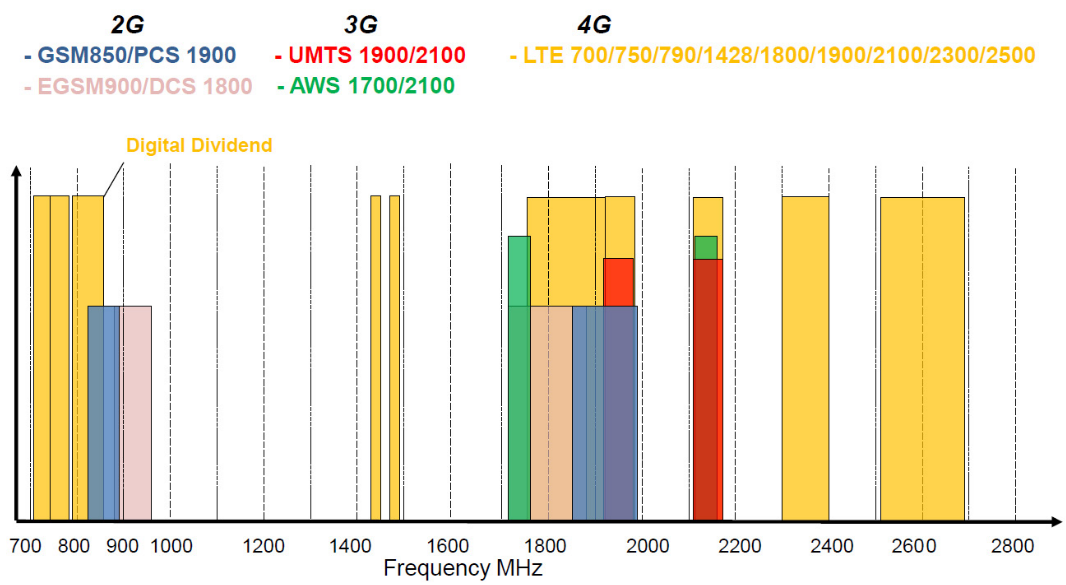
This whitepaper discusses Single Input Single Output ("SISO") and Multiple Input Multiple Output ("MIMO") antennas for use in 4G[1] LTE cellular technology.

Frequency Bands

As seen in Figure 1. *Cellular Frequency Bands*[2], in 2G cellular technologies, only certain bands were required for operation in most of the world—thus, a quad-band radio operating at four frequencies, with antennas in two basic ranges, was sufficient.

3G Cellular typically added two more bands in most regions: the AWS and UMTS frequency pairs of 1700/2100 MHz and 1900/2100 MHz.

Figure 1. Cellular Frequency Bands

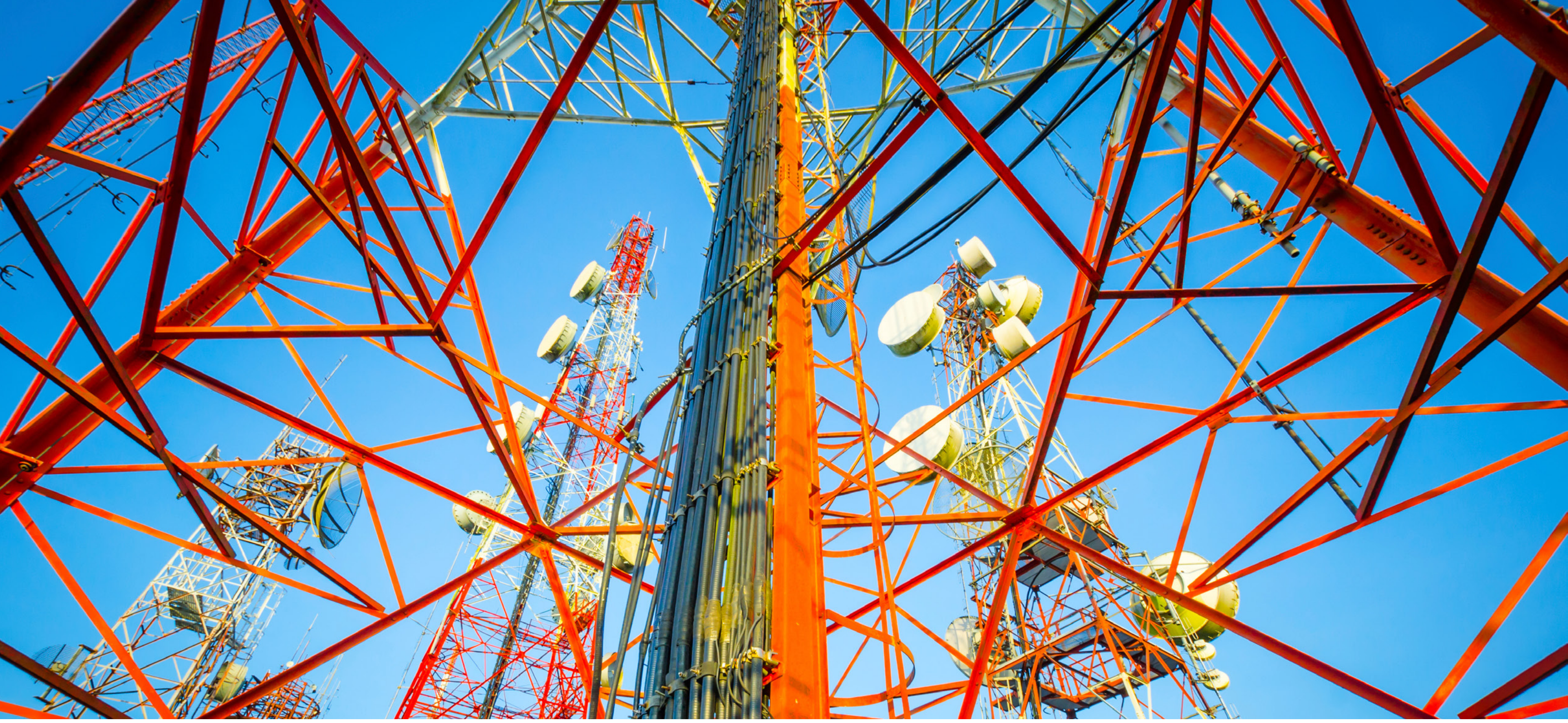


However, in 4G LTE, the number of available bands has increased dramatically—*particularly* if the cellular device is to be deployed in multiple areas of the world. Thus, LTE antennas need to support a wide-range of cellular frequencies: typically from 700 MHz to 2600 MHz to cover deployments today.

This support needs to include antenna parameters such as:

- Efficiency: The radiated power / power delivered to the antenna input (which takes into account mismatch loss, as well as antenna losses and losses in the surroundings).
- Return Loss: The amount of power that is reflected at the input to the antenna or device, due to a less than perfect impedance match.
- Isolation: A measure of power transfer from one antenna to another, also applicable to two-port antennas (such as dual-polarized or dual-band antennas)
- Correlation Coefficient: A measure of the correlation between antennas in a multi-antenna system for their radiation pattern characteristics.

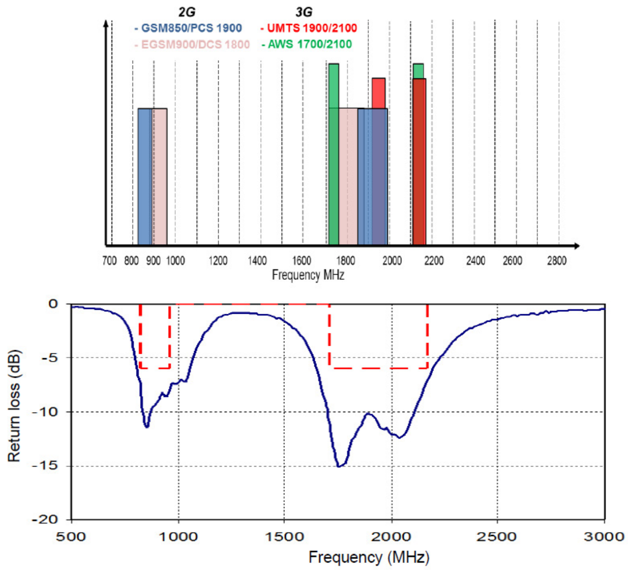
[1] Please see *Appendix A. Acronyms and Glossary* for more information.
[2] Many diagrams in this whitepaper are sourced from "Antenna and RF system Design Considerations for LTE Devices", paper by Ethertronics at DesignWest, San Jose, CA, April 2013.



2G and 3G Antennas

As seen in Figure 2. *Antennas for 2G and 3G Cellular*, a single dual-resonance antenna, with return loss better than -6dB, is sufficient for good performance for 2G and 3G cellular frequency bands. However, some devices choose to include a second diversity antenna (for the two *receive* frequency bands only).

Figure 2. Antennas for 2G and 3G Cellular



4G LTE Antenna Requirements

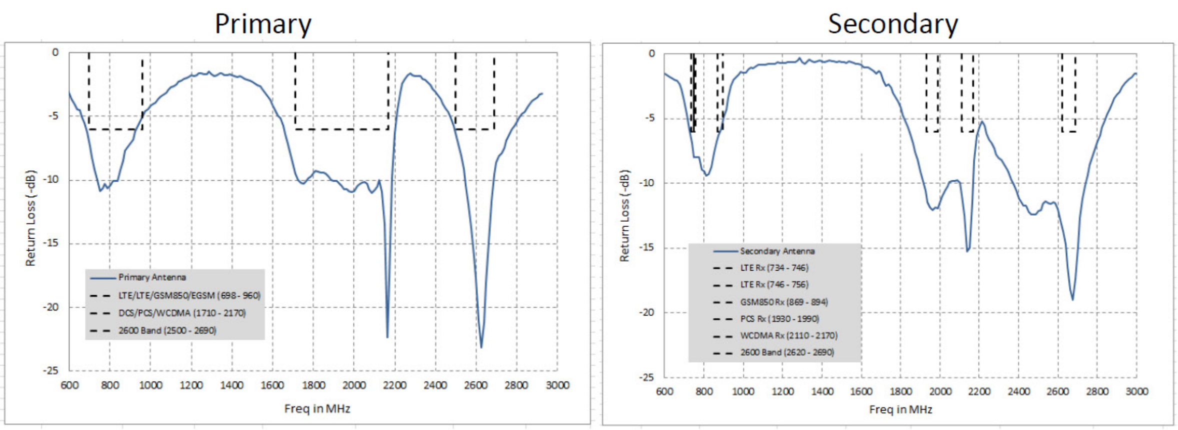
In general, 4G LTE deployments require two antennas on the mobile side—LTE cellular handsets and devices inside other equipment (such as laptop computers, USB data cards, and notepads) provide such dual antenna designs. Thus, the LTE cellular operators assume this capability in their LTE service deployments.

Ideally, both the antennas in a MIMO antenna must have the *same* Efficiency, a high Isolation *between* the two antennas, and a *low* Correlation Coefficient to achieve good LTE performance.

Table 1. Sample Specification for LTE Antenna System

Parameter	Value	Comments
LTE Bands (MHz)	700/850/900/1800/1900/2100/2300/2600	Up to 14 bands to include 2G & 3G compatibility
Return Loss	6 to 10 dB	
Efficiency	40 to 60%	Matched at the MIMO bands
Isolation	10 to 15 dB	High isolation at all LTE bands
Correlation	< 0.3	Required across all LTE bands

Figure 3. Required for 3G/4G Worldwide Antenna



- LTE – (698MHz – 746MHz)
- LTE – (746MHz – 787MHz)
- GSM850 – (824MHz – 894MHz)
- EGSM – (880MHz – 960MHz)
- DCS – (1710MHz – 1880MHz)
- PCS – (1850MHz – 1990MHz)
- WCDMA – (1920MHz – 2170MHz)
- 2600 Band (2500MHz – 2690MHz)

- LTE – (734MHz – 746MHz)
- LTE – (746MHz – 756MHz)
- GSM – (869MHz – 894MHz)
- PCS – (1930MHz – 1990MHz)
- WCDMA – (2110MHz – 2170MHz)
- 2600 Band (2620MHz – 2690MHz)

Secondary antenna needs to cover receive bands at LTE frequency bands; 6 discrete bands shown here

The charts in Figure 3. *Required for 3G / 4G Worldwide Antenna* show the typical performance required for the Primary and Secondary antenna in an LTE application for world-wide use. If an antenna is only used in certain regions, then fewer frequency bands can be supported in that design.

However, it can be expected that the number of useful bands are likely to continue to grow in each region. For example, carriers in the US have recently begun to deploy LTE at AWS frequencies (Band 4).

In these charts, the antenna pair covers Bands 1-10, 12, 13, 14, 17-20, 33, 35-39, and 41.

Receive Diversity (3G) and MIMO (4G)

3G Receive Diversity

In a 3G cellular system, Receive Diversity can be used to improve the reliability of the communication link. The Receive Diversity is implemented by adding a second (or more) "diversity" antenna to a cellular device. These additional antennas are generally spatially offset from the primary antenna, and may have different radiation pattern properties and/or different polarization properties.

The single stream transmitted from the base station is received by the two (or more) antennas in the cellular device to improve the probability of detection—thus providing better throughput and minimizing the effect of multipath fading.

Since there are two or more antennas, a "sample and switch" or "combining" technique is used to process the signals. For example, the effect of combining are shown in Figure 4. *Combined Antenna Streams*.

The plot in Figure 5. *Improvement in BER* shows the improvements in Bit Error Rate ("BER") for a set SINR for 2 and 4 antenna Receive Diversity, compared to a single receive antenna.

Figure 4. Combined Antenna Streams

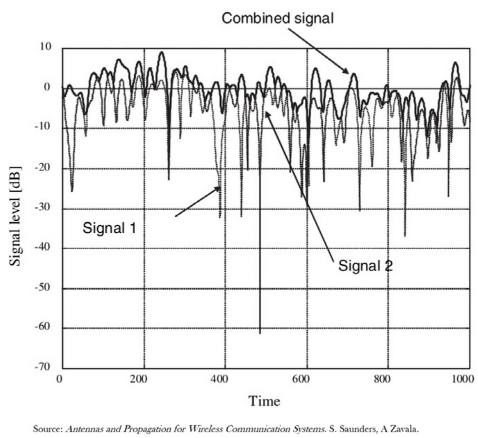
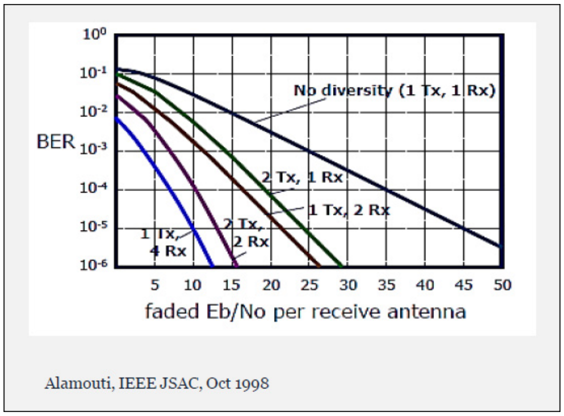


Figure 5. Improvement in BER



4G MIMO

In a 2x2 MIMO system, two data streams are transmitted from the base station over two separate propagation channels and received by two different antennas on the cellular device. Under ideal conditions, this results in an effective doubling of the data throughput.

Figure 6. *MIMO Basics* shows the MIMO antenna technique that uses two (or more) antennas *to take* advantage of multipath (that is present in every city) to increase the amount of data that can be transmitted across the cellular communication link.

Figure 6. MIMO Basics

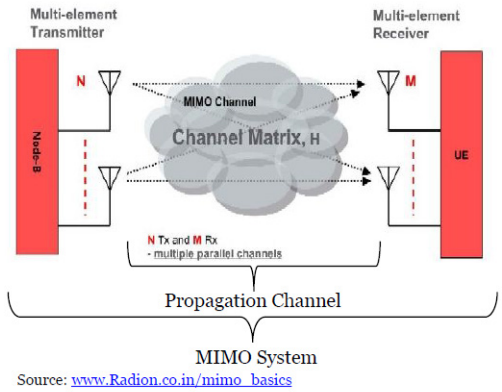


Figure 7. MIMO Average Capacity

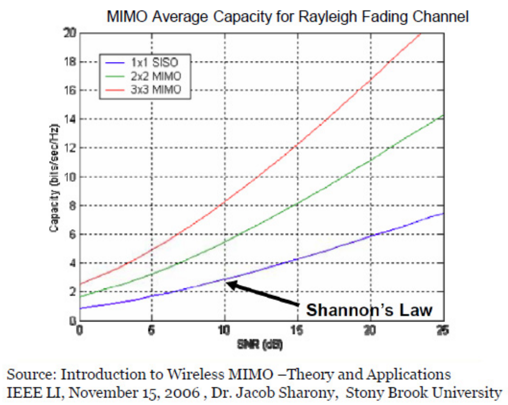


Figure 7. *MIMO Average Capacity* shows the capacity of SISO antennas versus 2x2 and 3x3 MIMO antennas.

MIMO is dependent on multipath to be present for the throughput improvements to be realized. *Carriers deploying LTE are generally assuming that cellular devices using LTE will be 2x2 MIMO to take advantage of the improved throughput*.

Multipath Channel Fading

FIGURE 8. TRANSMISSION ON A MULTIPATH CHANNEL

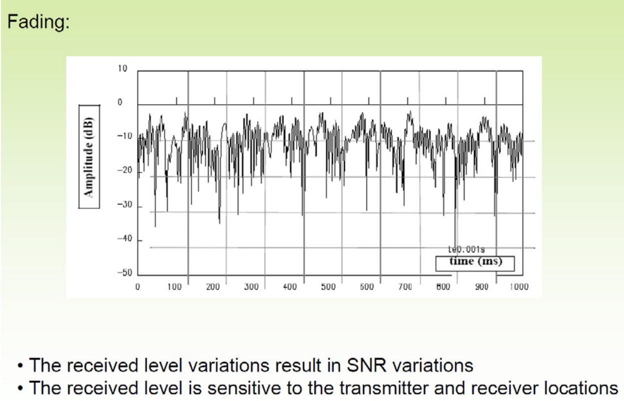


FIGURE 9. MIMO VS. SIMO / MISO

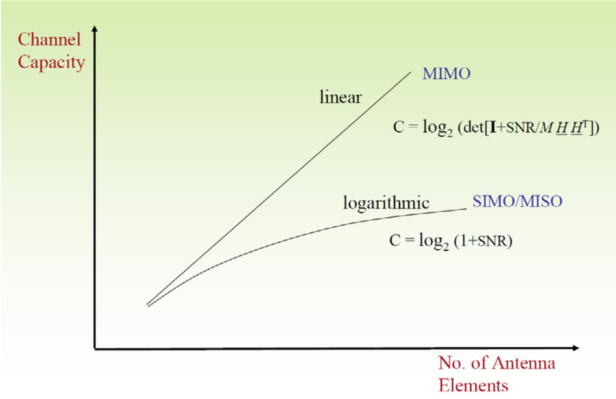


Figure 8. *Transmission on a Multipath Channel*[3] shows a typical multipath fading plot to re-enforce the issue that there are deep fades or signal drop-outs that can degrade the cellular communication link.

In cities, multipath is a reality—signals bounce off trees, buildings, etc., and continue to the receiver from different directions. A communications system that takes *advantage* of this will not suffer from fading losses. MIMO antennas take

[3] Figure 8 and Figure 9 are from a presentation entitled Introduction to *Wireless MIMO – Theory and Applications*, by Dr. Jacob Sharony, Director, Network Technologies Division, Center of Excellence in Wireless & IT, Stony Brook University.

advantage of this phenomenon rather than be affected by it—the receiving end uses an algorithm and/or signal processing to sort the multiple received signals and produces one signal with the original transmitted data.

Figure 9. *MIMO vs. SIMO / MISO* shows a theoretical plot of the benefit of using MIMO vs. MISO or SIMO antennas. In a MIMO system, there is a linear improvement in channel capacity with antenna elements, rather than the logarithmic improvement of a SIMO or MISO antenna system.

MIMO antennas and systems also improve the range of the transmission—each multi-path route is treated as a separate channel.

Pros and Cons

Clearly, using MIMO antennas for LTE provide significant advantages. However, these advantages come at some nominal cost—for example, the MIMO antennas are more expensive than SISO antennas.

In general, the following are the pros and cons for using SISO antennas in an LTE application:

Pros for using SISO:

- SISO antenna has a lower cost due to the single antenna design. The MIMO antenna will be higher in cost.
- In SISO, less volume is required for the single antenna compared to a two-antenna MIMO solution. Unlike smartphones, in an automotive or M2M application, this may not be a major advantage, since there is more room for multiple antennas and physical separation available for a MIMO antenna.
- Less power is required to drive a single receive port compared to a two receive port required for MIMO. This is more important in cell phones due to their limited battery capacity, and may not be an advantage for an automotive or M2M application.

Cons for using SISO:

- SISO has a significantly reduced data rate compared to MIMO in multipath conditions (urban canyon or in parking garage, for example). This can negate the advantage of using LTE for the application.
- SISO also has a reduced data rate in line-of-sight conditions. Since MIMO uses Spatial Multiplexing to encode multiple data streams in an M x N MIMO system, this provides a theoretical increase in data rate equivalent to MIN(M,N). Thus, in a 2x2 MIMO system, a 2 times increase in data rate is achievable over SISO.
- MIMO in line-of-sight conditions results in a power gain in the communication link which can result in improved data rate and link reliability.
- SISO has a lack of polarization diversity due to it being a single antenna solution. A 2x2 MIMO system can have different polarizations for the two antennas in a vehicle—this can improve data rates, and provide connectivity under conditions where the SISO antenna cannot communicate, due to the orientation of the single antenna relative to the base station.
- SISO has a lack of spatial diversity due to its single antenna design. A 2x2 MIMO provides spatial

diversity due to two antennas placed at different locations (the benefits are achieved for > ¼ wavelength spacing).

- Carriers have optimized their base stations antennas with the assumption that the cellular device uses, at least, a 2x2 MIMO antenna for LTE. Thus, the operation (and, potentially certification) of a SISO antenna may be problematic.

Summary

In general, it is possible to use a SISO antenna for an LTE application deployment—whether automotive or other M2M mobile device. However, we recommend that a minimum of a 2x2 MIMO antenna should be used for LTE—the performance advantages, and potential for avoiding operational problems, outweigh the lower cost and lower port power requirements of a SISO antenna.

Contact Aeris at info@aeris.net or 1-888-GO-AERIS for more information.

Appendix A. Acronyms and Glossary

1xRTT	Single Carrier Radio Transmission Technology (used in ANSI-2000 CDMA).
1xEV-DO	Enhanced Voice-Data Only (also Enhanced Voice-Data Optimized)
2G	Second Generation Cellular
3G	Third Generation Cellular
3GPP	3rd Generation Partnership Project (GSM family of cellular technologies)
3GPP2	3rd Generation Partnership Project 2 (CDMA family of cellular technologies)
4G	Fourth Generation Cellular
ANSI-41	American National Standards Institute Standard 41, for control signal messaging on SS7
ANSI-2000	American National Standards Institute Standard 41, for CDMA2000 cellular
BS	Base Station
CDMA	Code Division Multiple Access
EV-DO	Enhanced Voice-Data Only (also Enhanced Voice-Data Optimized)
GGSN	Gateway GPRS Support Node (see also SGSN)
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communication
GSM MAP	GSM Mobile Application Part, for control signal messaging on SS7
HLR	Home Location Register
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access
HSPA+	Enhanced or Evolved High Speed Packet Access
HSUPA	High Speed Uplink Packet Access
IMSI	International Mobile Subscriber Identifier (used in GSM and CDMA)
LAN	Local Area Network
LTE	Long Term Evolution
MAP	See GSM MAP
MDN	Mobile Directory Number (used in CDMA—conceptually similar to the MSISDN in GSM)
MEID	Mobile Equipment Identifier (used in CDMA)
MIMO	Multiple Input, Multiple Output (in the context of antennas)
MS	Mobile Station (cellular radio handset, or cellular M2M device)
MSC	Mobile Switching Center
SGSN	Serving GPRS Support Node (see also GGSN)
SISO	Single Input Single Output (in the context of antennas)
SMS	Short Message Service
SMSC	Short Message Service Center
SS7	Signaling System 7
UMTS	Universal Mobile Telecommunications System
VLR	Visited Location Register
WAN	Wide Area Network