

## Performance analysis and evaluation of LTE-based wireless private network for grid communications

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**Abstract:** In this paper, coverage, capacity, and delay of LTE-based wireless private network are investigated. Coverage and signal fading of LTE-230 system and LTE-1800 system are analyzed theoretically. The system capacity and transmission delay of LTE-230 and LTE-1800 system is compared from the perspective of protocol process. The real network testing verified the analysis result. The LTE-230 system has better performance in coverage. In terms of transmission rate and delay, in the case when the LTE-230 system has a lower transmission power, it obtains similar performance of LTE-1800.

### 1. Introduction

The power wireless private network is an important communication infrastructure for implementing smart grids. Traditional power wireless networks use public or private communication networks, including IEEE 802.11, cellular networks, radio data transceiver [1, 2], etc. However, critical services, especially load control services, require strict delay requirements and special security guarantees [3, 4]. In China, the policy explicitly requires that such critical services cannot be transmitted over public communication networks. Therefore, considering the special needs of critical services, as well as economic reasons, the use of wireless private network construction has greater potential. In the current wireless private network construction, using LTE (Long Term Evolution) technology to provide high-rate services is a mainstream solution [5, 6]. Among them, countries such as Indonesia and China use the 1800MHz frequency band to carry out LTE services [7]. In China, within a decade, the State Grid Corporation of China organized a series of experimental tests to evaluate the performance of using the 230MHz frequency band to carry load control services [8]. Henceforth the system using 1800MHz is called "LTE-1800" and using 230MHz is called "LTE-230".

Since wireless communication networks that support grid operations are deployed in large numbers in cities and villages, there are special requirements for network coverage, capacity, and delay. Some scholars have carried out relevant theoretical research on this. Jingping and Weiwei proposed a ray-tracing-based approach to analyze the coverage of TD-LTE wireless private networks [9, 10]. Jinping et al. theoretically analyze the coverage and rate issues of the LTE-230 system [11].

Reference [12] compares the performance of LTE-1800 and LTE-230. In the analysis, the occupied bandwidth of the two systems is different. Therefore, the experimental results on throughput and delay are not convincing. According to the research conclusion, the author proposed a solution for the hybrid network of TD-230 and TD-1800 [13]. In addition, some scholars have carried out research on the coverage optimization problem of LTE-based power wireless private network [14, 15].

Due to the particularity of the wireless communication environment and the complex impact of communication protocol design on communication performance, in addition to carrying out relevant

theoretical research, relevant manufacturers and operating companies have also carried out relevant experimental network construction and experiments. In order to clarify the differences in system coverage, user capacity, and delay between TD-230 and TD-1800 networks, we conducted relevant theoretical analysis and experimental network verification.

The main contributions of this paper is as follows:

- Analyzing the comparison between coverage and signal fading of LTE-230 system and LTE-1800 system, carrying out the real network test comparison of the system under different propagation environments and comparing the performance of the two systems from theoretical and real network tests;
- From the perspective of protocol design, analyzing the system capacity of LTE-230 system and LTE-1800 system;
- From the perspective of protocol interaction, analyzing the delay performance of LTE-230 system and LTE-1800 system, and giving the real network test conclusion.
- Evaluate the LTE-230 and LTE-1800 system in term of throughput and delay and analyze the performance difference.

## **2. LTE-based wireless private networks**

### **2.1 LTE-230 system**

The LTE-230 system, based on the public network TD-LTE, changes the frequency band to 223~235MHz. This frequency band consists of 420 25KHz frequency points, which are used by 8 authorized users, such as military, meteorology and the state grid company, and amateur stations. In order to avoid interference within the system, the operating frequency of each authorized user is not continuous. Thus, the spectrum aggregation technique must be used, so that using OFDM techniques at the discrete frequency to obtain a higher transmission rate.

### **2.2 LTE-1800 system**

LTE-1800 is based on public network TD-LTE frequency changing, working in the 1800MHz frequency band (1785~1805MHz). This system has same key system indicators with the public network TD-LTE system such as capacity, security measures, and minimum scheduling granularity of frequency resources, allocation scheme of uplink and downlink resources, and transmission delay. For example, the minimum spectrum resource required for networking is 5 MHz, and the minimum schedulable spectrum bandwidth of the terminal is 180 kHz. It is suitable for services with continuous spectrum resources and uplink and downlink symmetric services or downlink-based services.

The main technical features of the two systems are shown in Table 1.

Table 1: Comparison of LTE-230 and LTE-1800 system

	LTE-230	LTE-1800
<b>Reference Standard</b>	3GPP 4G	3GPP 4G
<b>Duplex model</b>	TDD	TDD
<b>Key technology</b>	OFDM	OFDM
<b>Modulation and coding</b>	64QAM/16QAM/QPSK, Adaptive	64QAM/16QAM/QPSK, Adaptive
<b>MIMO</b>	Nonsupport	support
<b>Frequency</b>	223~235MHz	1785~1805MHz
<b>Discrete frequency</b>	support	Nonsupport
<b>Intra-band interference avoidance</b>	Support	Nonsupport
<b>Carrier Aggregation</b>	Support ( Aggregation in 25 kHz )	Not supported ( need to work in continuous spectrum )

### 3. Performance analysis

#### 3.1 Network coverage analysis

Okumura-hata transmission model is suitable for the frequency band 150~1500MHz, COST231 propagation model is suitable for the frequency band 1500~2000MHz. So the LTE-230 system is suitable for the Okumura-hata transmission model, LTE-1800 system is suitable for COST231 propagation model. Under the same transmission environment and the same installation conditions, the attenuation rate of radio waves increases with the increase of frequency, and the coverage capability decreases with the increase of frequency.

The pathloss (in dB) of Okumura-hata model is written as

$$PL^1 = 69.55 + 26.16 \times \lg(f) - 13.82 \times \lg(h_b) - a(h_m) + [44.9 - 6.55 \times \lg(h_b)] \times \lg(d) + c \quad (1)$$

The pathloss (in dB) of COST-231 model is written as

$$PL^2 = 46.3 + 33.9 \times \lg(f) - 13.82 \times \lg(h_b) - a(h_m) + [44.9 - 6.55 \times \lg(h_b)] \times \lg(d) + c \quad (2)$$

Where  $f$  is the frequency in MHz and  $d$  is the distance in km.  $h_m$  is the height of terminal antenna,  $h_b$  is the height of base station antenna. The function  $a(h_m)$  and the factor  $c$  depend on the environment which is described in [16] in detail.

We evaluate the pathloss of COST 231 and Okumura-hata under the same  $h_b$ ,  $h_m$ ,  $c$ ,  $d$  and  $a(h_m)$ . The difference of the pathloss between the two models is:

$$\begin{aligned} D &= PL^2 - PL^1 \\ &= \{46.3 + 33.9 \times \lg(f_{1800}) - 13.82 \times \lg(h_b) - a(h_m) + [44.9 - 6.55 \times \lg(h_b)] \times \lg(d) + c\} \\ &\quad - \{69.55 + 26.16 \times \lg(f_{230}) - 13.82 \times \lg(h_b) - a(h_m) + [44.9 - 6.55 \times \lg(h_b)] \times \lg(d) + c\} \\ &= 25.3209 \end{aligned} \quad (3)$$

That is, the COST231 model at the same conditions and the same distance is 25.3209 dB larger than the Okumura-hata model.

From Eq. 1 and 2, we can find that the larger the distance, the larger the absolute value of the pathloss. However, the relationship between pathloss and distance is nonlinear. As the distance increases, the coverage loss caused by the same pathloss gradually increases.

#### 3.2 System capacity analysis

The LTE-230 system supports the terminal in real-time online, and the terminal is always in an active state to ensure that the terminal service can be scheduled timely and fast, as well as the terminal

does not need to re-establish the air interface RRC connection establishment when the service arrives, and access to the system side. In theory, the number of online users can be many, but since the terminal is online in real time, the base station side needs to store the terminal signaling and the context information of the service bearer RB, and the user plane needs to listen to the common channel, so the number of online users is limited by the memory and processing of the base station device ability.

The parameter related to the terminal access capacity in the LTE-230 system design is C-RNTI (Cell Radio Network Temporary Identifier). When the terminal accesses the LTE-230 system, the base station allocates a C-RNTI value to the terminal to identify the terminal and scramble. The terminal is identified by the resident sub-band number and the C-RNTI in the base station. The currently designed C-RNTI length is 7 bits. According to the 40 sub-bands of the 1MHz spectrum, the number of access terminals supported by the single base station is 5120. If more terminals need to be supported, only the length of the C-RNTI need be increased. However, due to the limited memory and processing capacity of the base station equipment, the terminal access capacity of the LTE-230 is set to 3000/sector.

The LTE-1800 access capacity is as same as that of the operator's public network. Operators in China have put forward specific capacity requirements for equipment suppliers' wireless devices: the number of cell activation users of a single 20M bandwidth is not less than 400, and the number of online users is not less than 1200.

In order to satisfy the number of simultaneous activation users up to 400, each module of the eNodeB wireless protocol stack can simultaneously save context information of 400 UEs. In order to meet the number of simultaneous online users, the radio resource control (RRC) module, GPRS tunneling protocol user plane (GTP-U), packet data convergence protocol (PDCP) and other modules can simultaneously save context information of 1200 user equipments (UEs). The eNodeB manages the state of the UE on the basis of the established process, according to the service situations of the users, and satisfies the requirement of the cell capacity while ensuring the user service.

### 3.3 Communication delay analysis

The LTE 1800 terminal access mechanism is as same as the public network TD-LTE. The wireless terminal is working in an active state, a resident state, or a sleep state according to the busy state of the service. And the delay from the sleep state to the active state is 50 ms. The delay from the resident state to the active state is 100ms.

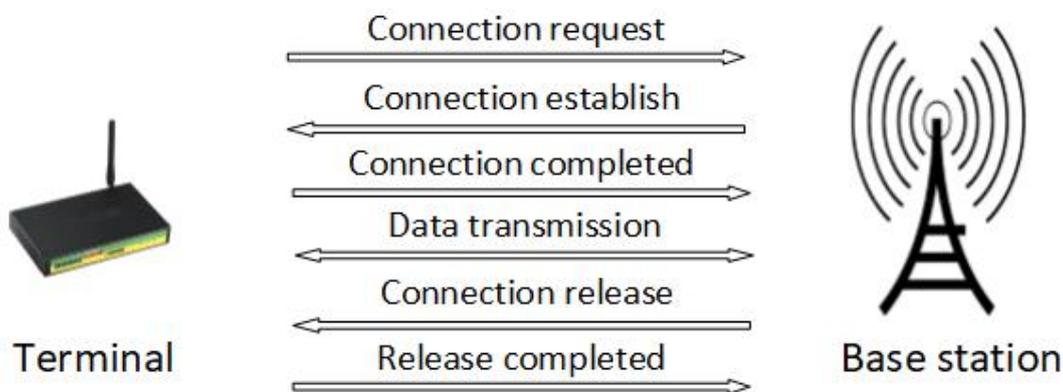


Figure 1: Signaling interaction and data transmission process

The complete service transmission includes multiple stages such as connection establishment, data transmission, and connection release which are shown in Fig. 1. Furthermore, the transmission delay is also composed of control plane delay and service plane delay.

According to the above analysis, the LTE-1800 control plane delay is 50~100ms. From the business level analysis, the delay is guaranteed to be 100ms.

The theoretical minimum of the one-way delay of the user plane is 5ms. At present, the HARQ operating point in the field test of the LTE system is usually between 10% and 15%. The two-way transmission delay is 20~25ms. The two-way delay of the field test is generally 30~60ms.

The total delay of the LTE-1800 bidirectional transmission is the control panel delay plus the user plane delay, which is between 70 and 190ms.

For LTE-230, under the premise of satisfying the access of massive users, realizing the fast scheduling of terminals is a necessary guarantee for the system. While simplifying the access process, LTE-230 changes the idea that a large number of users in the traditional wireless system are queued for scheduling. For each terminal, the system reserves an uplink control channel for the scheduling request of the terminal. When the terminal has data to send, the scheduling request can be sent through the pre-assigned control channel.

The above mechanism simplifies the terminal access process, shortens the terminal access delay, and sets the terminal priority according to different services to improve the communication requirements of real-time demanding services such as distribution automation.

Since the LTE-230 terminal is online in real time, the data transmission only has user plane delay, and the data transmission includes data paging, semi-static access and data transmission at reserved resource points, and transmission confirmation. The required duration is 3 physical frames, the LTE-230 physical frame duration is 25ms, the transmission delay is 75ms, and in the case of data retransmission, 2 radio frame durations are added, and the bidirectional transmission duration is about 125ms.

#### 4. Experiment evaluation

The capacity analysis of wireless communication systems often completes the analysis of maximum capacity according to the Shannon formula. However, in practical systems, communication throughput is difficult to reach the maximum capacity of the system due to problems such as the design of the communication protocol. In addition, in the analysis of throughput, it is necessary to consider the difference of specific system parameter configuration. For example, MIMO technology can be used in the 1800MHz band, but only single antenna can be used in the 230MHz band. In addition, differences in antenna design, gain and coding scheme of two systems, etc., will impact on system performance. Therefore, in order to evaluate the performance of the two systems, we selected two companies' equipment for on-site testing and conducted a comparative analysis of the experimental results.

The experimental equipment selected the LTE-230 system of China Potevio Research Institute and the LTE-1800 system of TD-Tech. The LTE-1800 system uses a dual-interface 8-antenna MIMO antenna. The transmit power per antenna is 10W. The experimental site was selected in Meishan City, Guangdong Province, with 16 km of suburban roads and 16 km of mountain roads (as shown in Figure 4). The suburban roads are wide and flat, and the trees and mountains in the mountainous roads are seriously blocked. The specific device parameters are shown in Table 2. It should be noted that 5 1-MHz terminals were used for LTE 230 system testing due to the lack of 5-MHz terminals.

The experimental test uses FTP service transmission. The experimental results are shown in Fig. 3. It can be seen from that although the LTE-1800 system adopts MIMO technology and increases the transmission power of the base station and the terminal, but since the LTE-230 system can exhibit the wide coverage of the low-band system, the coverage is still better than the LTE-1800 system.

In terms of uplink data rate, the LTE-230 system is better than the LTE-1800 system in the most test segment. In terms of downlink maximum data rate, the LTE-1800 system can take advantage of MIMO performance, and the downlink peak rate is better than the LTE-230 system. In places with poor signal, MIMO system is difficult to play a performance advantage. Due to the lower frequency, LTE-230 has larger coverage radius than LTE-1800. LTE-230 has an uplink coverage radius of 28km and a downlink of 26km. Correspondingly, the uplink and downlink coverage radius of LTE-1800 is about 17km.

In terms of delay, the delay of the LTE-1800 system in the optimal signal environment is better than that of the LTE-230 system. However, the LTE-1800 system cannot maintain a connection for a long time, and needs to re-initiate random access when the service is initiated. Therefore, its business delay will be reduced to 150ms. The terminal of the LTE-230 system is real-time online. Once the terminal is connected, it is always online. The service can be initiated at any time without random access, which is always 150ms. According to the demand of power load control service, the delay of the two systems both meets the service requirements.

## 5. Conclusion

This paper focuses on the system selection problem in the construction of power wireless private network, and compares two LTE-based wireless private network solutions. From the perspective of theoretical analysis, this paper compares the coverage, capacity, and delay of the two systems. In addition, in order to be closer to reality, the coverage, delay and throughput rate of the two systems were compared through the real network test.

From the analysis and testing, the LTE-230 system has better performance in coverage. In terms of transmission rate and delay, in the case when the LTE-230 system has a low transmission power, it obtains similar performance of LTE-1800. The network test results verified our analysis well.

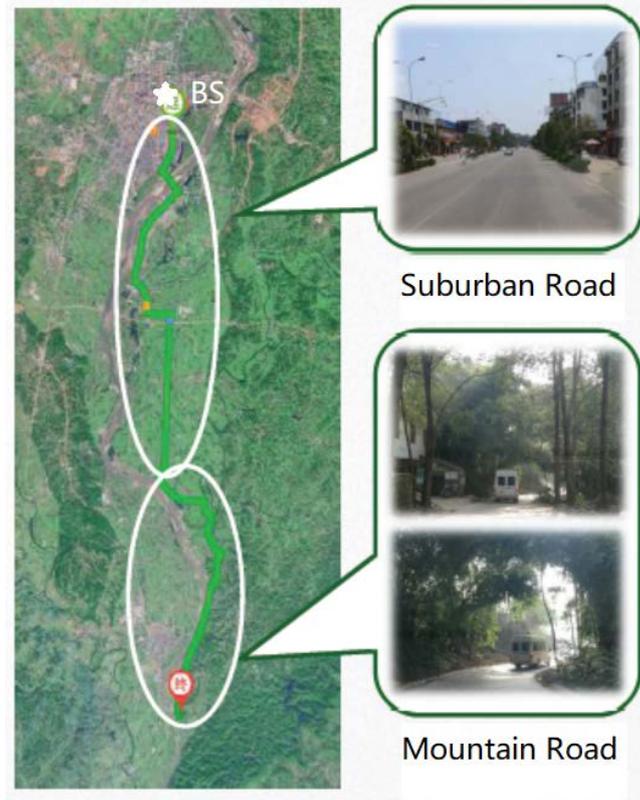


Figure 4 Experiment Environment

Table 2 Comparison of equipment parameters

	LTE-230	LTE-1800
Frequency [MHz]	223-235	1785-1805
Bandwidth [MHz]	5	5
Number of BS Antenna	1	4*2
BS Transmit Power [W]	6	80 (MIMO with 8 antennas)
MS Transmit Power [W]	0.2	2
Antenna Gain of BS [dBi]	10	18
Antenna Gain of MS [dBi]	7.5	7.5

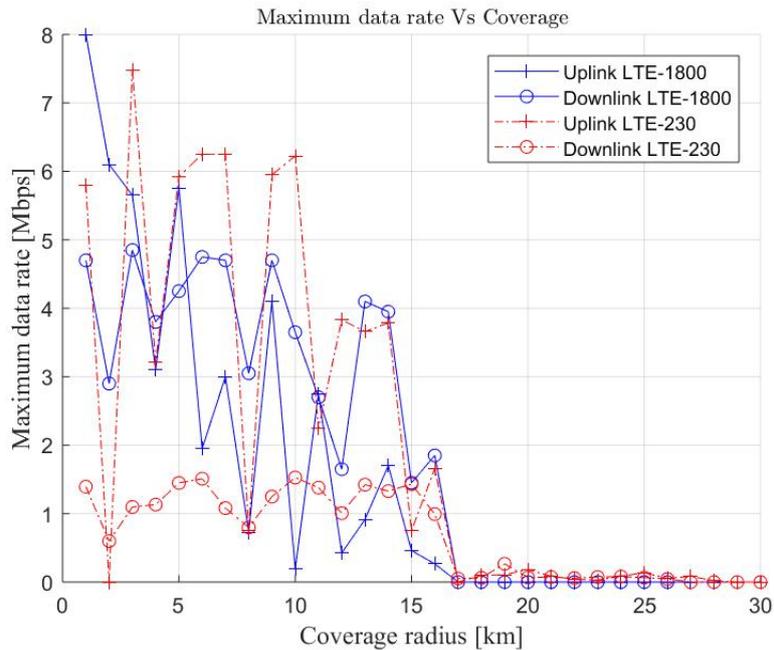


Figure 3. Maximum data rate Vs Coverage radius

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