5G Network Performance Evaluation and Deployment Recommendation Under Factory Environment

Kaiyue Zeng[1], Wei Deng[1], Rui Wang[1], Long Zhang[1], Jinxia Cheng[1], Tao Chen[2], Na Yi[3]
[1]China Mobile Research Institute Co., Ltd., Beijing, 100053;
[2]VTT Technical Research Centre of Finland Ltd, Espoo, FI-02150, Finland ;
[3]Institute for communication Systems, University of Surrey, UK, GU2 7XH
e-mails: {zengkaiyue, dengwei, wangrui, zhanglong, chengjinxia}@ chinamobile.com, tao.chen@vtt.fi, n.yi@surrey.ac.uk

Abstract— **Industrial scenarios put forward higher demands on data rate, latency and reliability of 5G networks. In order to further promote the integration and applications of 5G with the industrial field, a 5G network performance evaluation scheme based on factory environment is discussed in this paper. Moreover, to further reduce the transmission and circuitous route latency, a local user plane function (UPF) is also proposed. Combined with the wireless channel propagation model considered in factory scenario, latency, reliability performance and the relationship between data rate and distance are evaluated in a specific environment. It is shown through the measurement results, the proposed local UPF solution could reduce latency around 20%. Finally, recommendations on construction of 5G network in a typical factory environment are also given in this paper.**

Keywords—low latency, local traffic offloading, high reliability, rate-distance distribution evaluation, local user plane function

I. INTRODUCTION

Due to the large bandwidth, high reliability, low latency, and wide connectivity, 5G can provide promising solutions for industry-oriented application. Especially, the deep integration of 5G in industry could enable the digital transformation of the manufacturing industry.

China has spent lots of efforts to promote the deep integration of 5G with industry systems. In addition to the policy support from the government, many research projects have been funded on 5G industrial applications. These applications cover a wide range of industry sectors, including, but not limited to, automobile, harbour and smart grid. 5G experiments have been conducted with Volkswagen China, Ningbo Zhoushan harbour, Shanghai Commercial Aircraft Corporation, Southern Power Grid, etc.

However, the integration of 5G with industrial applications still faces lots of challenges. These include the ultra-high data rate requirements for industrial visual quality inspection and other applications; the real-time, certainty and reliability requirements for Programmable Logic Controller(PLC) and other industrial field applications [1]. 5G technology needs further development to support industry use cases. This motivated us to test the related KPIs in the practical industry scenarios and discuss the measurement results to further understand them, and give some recommendations based on the measurement results analysis.

In this paper, the evaluation methods of latency, reliability, data rate and field performance are discussed. Based on the test evaluation results, recommendations of the parameter configuration suitable for factory networking are analyzed to meet the requirements of the considered factory scenarios.

II. LATENCY PERFORMANCE EVALUATION BASED ON LOCAL TRAFFIC OFFLOADING

A. Standard UPF Sinking Scheme

More and more industry sectors are undergoing digital and informatization transformation. Advanced network technologies play the important role to support such a digital transformation. The upgrade and transformation of the factory puts forward the requirements of low cost, high security level, high isolation level, and localized service for the 5G industry private network. At the same time, industrial control systems have strict requirements for latency. In most industrial applications, the end-to-end latency is required to be less than 20ms [2]. For example, a remote bridge crane controller in a harbour requires the end-to-end latency of 18ms. In some special industrial scenes, some latency-sensitive services, such as PLC control system of robot arms, require the end-to-end latency to be less than 10ms [2]. To meet the low latency requirement, the UPF of the network need to be deployed closed to the user equipment side. The UPF sinking scheme is proposed to satisfy this need.

A typical UPF scheme is show in Figure 1, in which, the UPFs are deployed in the core layer of network operator's 5G networks. From the perspective of UPF offloading routing, on the one hand, The metro transmission network between the base station and UPF causes significant latency. On the other hand, the offloaded data needs to be transmitted between the UPF at core and the server at the factory through a dedicated line , which also increases the latency of the circuitous route.

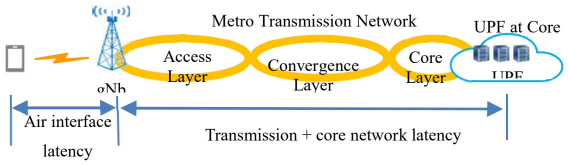


Figure 1. Standard UPF.

B. Local UPF Sinking Scheme

In order to reduce the transmission and the circuitous route latency, a local UPF scheme, as shown in Figure 2, is proposed in this paper. In this new scheme, the UPF is directly deployed in the local area of the factory, so the business data of factory can be directly offloaded to business server via an optical fiber in factory, which reduces the latency from the metro transmission network, and the time to transmit business data from the UPF at core to the server at factory as well.

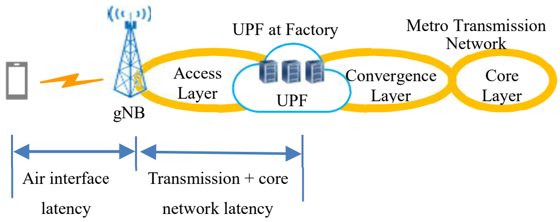


Figure 2. Local UPF.

To obtain the latency performance of two different UPF deployment schemes, the latency field test has been carried out based on a factory environment in Zhejiang Province.

C. Field Test

- *Test environment*

In standard UPF scheme, the UPF is deployed in the convergent data center of the prefecture, and the data after unloading is routed to the business sever of the factory via a dedicated line with a distance of 21.6 km. In local UPF scheme, the UPF of the factory is deployed together with the BBU of the factory, and the optical fibre distance of the business sever is 2 km as shown in Fig. 3. The different routing between standard UPF and local UPF are explained as below:

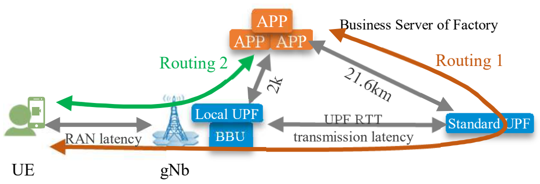


Figure 3. Different routings between standard UPF and local UPF.

standard UPF routing1： UE <—>gNB <—> UPF at Core<—>The Dedicated Line<—>Factory App

local UPF UPF routing2： UE <—>gNB <—> UPF at Factory <—> Factory App

The test-related parameter settings are given in Tab. 1 as follows:

Table 1. Latency trial conditions.

Parameters	Value
BS	DAS，Single layer
Carrier frequency	2.6 GHz
Duplex mode	TDD
Frame structure	5ms TDD-DL-UL-Pattern S:10:2:2 D D D D D D D S U U
UE Tx power	23dBm
BS antenna configurations	4 Tx/4 Rx antenna ports
UE antenna configuration	1 Tx/1 Rx antenna ports
Bandwidth	100 MHz
SCS	30 kHz
Pre-scheduling	Off
SR cycle time	10slot（5ms）
RSRP	-70dB
SINR	20dB

It is worth noting, since the purpose of the test is to compare the transmission latency, it only guarantees that the air interface latency has the same configuration. Moreover, the configuration is not optimized, namely, the pre-scheduling switch has been turned off.

- *Test method and results*

The same UE performs a fixed-point latency test in the factory and sends a Ping packet to the factory server based on the standard UPF scheme and the local UPF scheme. The packet size includes three settings of 60bytes, 512bytes, and 1024bytes. Under each packet length configuration, sending 100 packets each time and repeat 3 times. The average latency results are shown in Tab. 2:

Table 2. Latency trial results

	Standard UPF			**Local UPF**		
Packet size(bytes)	**60**	**512**	**1024**	**60**	**512**	**1024**
3x100packet Average latency (ms)	10.068	11.441	10.678	8.017	9.822	6.872
	10.485	10.636	11.028	8.944	8.239	9.339
	10.771	11.169	11.305	7.876	8.843	9.022
Average latency (ms)	10.441	11.082	11.003	8.279	8.968	8.411

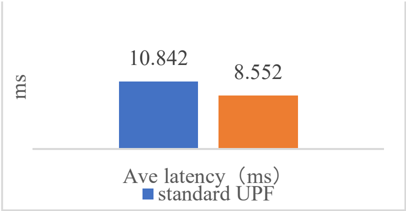


Figure 4. Average latency trial results of standard UPF and local UPF.

- *Test conclusions and deployment recommendation*

It can be seen from the above test results in Fig.4, that the local UPF latency for all tested packet size is significantly lower than the standard UPF latency. Further considering the average latency under all kinds of packet sizes, the result of standard UPF scheme is 10.842ms, and local UPF scheme is 8.552ms. The average latency has been reduced about 20% with the proposed local UPF, which can better performance to meet the latency requirements of industrial control systems (i.e., <10 ms). For the standard UPF scheme, most UPFs are farther away from the factory, up to 20~300km. Therefore, in actual scenes, compared with the standard UPF scheme, the latency performance of the local UPF will be more obvious. Based on the above observations, it is recommended to adopt the local UPF deployment scheme to achieve better latency performance for the scenarios with sensitive latency requirements.

III. Reliability Performance Evaluation

According to 3GPP, reliability refers to the probability of successful transmission of packets from the originating end to the receiving end under specific channel conditions and specific transmission latency requirements[6]. 3GPP R15[3] introduces a set of new features to improve the reliability. Just list a few: initial BLER, low bit rate table, PDCP repetition, slot repetition. However, with the development of the Industrial Internet, industrial control systems such as PLC, Computer Numerical Control Machine Tools, the requirement for reliability is still very strict and expected to be above 99.999%~99.9999% [8]. For this reason, 3GPP R.16[5] further proposed the method of DCI enhancement to promote the reliability performance, and provide high reliability guarantee for industrial applications [5]. Based on the above technologies, we carried out a set of field tests to evaluate the reliability capability.

A. Test Method

- *Reliability capability level*

In order to match the capability requirements for reliability in different scenarios of the industry, the following hierarchical configuration of reliability level based on different reliability technologies are considered in our work as shown in Tab.3.

Table 3 Reliability level configuration

Reliability Level			**Level1**	**Level2**	**Level3**
Resource Scheduling Strategy	Data channel	Initial BLER	0.001%	1%	10%
		Low Bit Rate Table	√	×	×
		RLC Model	AM	UM/AM	UM/AM
		PDCP Repetition	√	×	×
		Slot Repetition	√	×	×
	Control Channel	CCE AL 16	√	√	×
		Long PUCCH Format	√	×	×
		DCI Enhance（R16）	√	×	×
		PUCCH Repetition	√	×	×

Among them, the reliability capability of Level 1, Level 2 and Level 3 is expected to decrease gradually. Since some features in Level 1 are not currently supported by the industry, the reliability capability of Level 2 and Level 3 were tested and the results are presented in the following sections.

- *Reliability based on latency level*

Considering the latency requirements and network capabilities of the industry, the reliability based on end-to-end latency requirements of 10ms, 20ms, 30ms and 50ms is respectively evaluated.

- *Reliability statistical method based on packet latency CDF distribution*

The reliability value is obtained by making CDF distribution statistics for all Ping packets' latency in each test scenario, and then taking the distribution proportion corresponding to the above latency levels, namely, the corresponding reliability capability under each latency requirement.

- *The influence of packet size and interval time on reliability testing efficiency*

Owing to reliability testing requiring a long time to accumulate enough samples, testing generally takes a fairly long time. When the packet length exceeds 1400bytes, additional latency caused by subcontracting will be increased. At the same time, the larger the packet interval time, the longer the overall testing time. In order to improve the efficiency of reliability testing, small packet length and short interval time should be adopted as far as possible. Therefore, in this test, the packet size was set to 80bytes and the interval time was set to 50 ms.

B. Test environment

In order to obtain enough test samples to have statistical significance, lab test and factory test in Liaoning province were carried out respectively. There are totally 10 test terminals respectively placed in excellent RSRP point, good RSRP point, medium RSRP point and low RSRP point. The terminals at four points are 1:2:4:3. The success rates of Ping under each test condition were calculated respectively.

It is worth to point out, the selection of excellent point, good point, medium point and low point is based on the RSRP CDF obtained through the actual environment traversal. In the CDF curve, RSRP corresponding to 5% is taken as low point, 50% as medium, 90% as good and 95% as excellent.

C. Test Conditions

The considered test conditions in our work are given in Tab. 4 as shown as below.

Table 4 Reliability trial conditions

Parameters	Value
BS	Indoor Single Pico Site
Carrier frequency	2.6 GHz
Duplex mode	TDD
Frame structure	5msTDD-DL-UL-Pattern S:10:2:2 D D D D D D D S U U
UE Tx power	23dBm
BS antenna configurations	4 Tx/4 Rx antenna ports
UE antenna configuration	2 Tx/4 Rx antenna ports
Bandwidth	100 MHz
SCS	30 kHz
Packet size	80Bytes
Packet interval time	50ms

D. Results evaluation

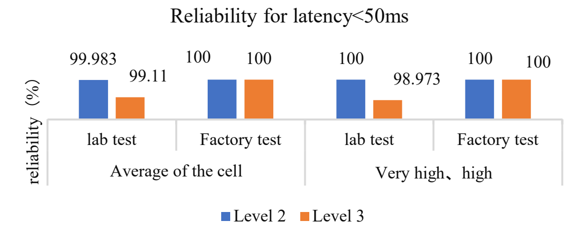
The reliability values shown in Tab. 5, are based on two different reliability configurations, Level 2 and Level 3. CDF statistics are made for all Ping packet latency in each test scenario, and then the CDF ratio corresponding to the latency of 10ms, 20ms, 30ms and 50ms is taken, namely, the corresponding reliability level under each latency requirement.

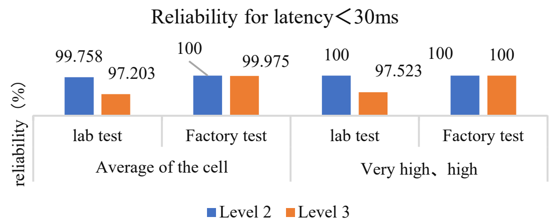
Table 5 Reliability trial results for different levels

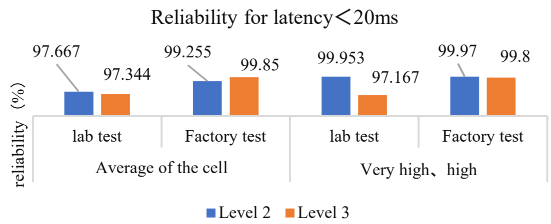
Reliability performance（%）			<50ms	<30ms	<20ms	<10ms
Reliability level	Testing scenarios	Testing points（According to RSRP）				
Level 2	Lab test	Average of the cell	99.983	99.758	97.667	46.584
		Excellent/good	100	100	99.953	76.383
	Factory test	Average of the cell	100	100	99.255	39.565
		Excellent/good	100	100	99.97	43.21
Level 3	Lab test	Average of the cell	99.11	97.203	97.344	67.896
		Excellent/good	98.973	97.523	97.167	77.62
	Factory test	Average of the cell	100	99.975	99.85	43.205
		Excellent/good	100	100	99.8	45.135

In the Table 5, *the blue area represents the reliability test result ⩾99.9%; the green area represents the reliability test result ⩾99%; the remaining test results are reliability <99%.* Average of the cell has a total of 100,000 points; Excellent/good has a total of 30,000 points.

Reliability results under each latency requirement are analysed.







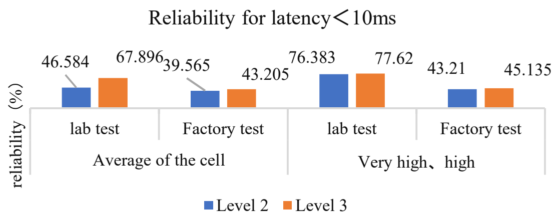


Figure 5. Reliability performance under each latency requirement.

- *Different reliability performance between level 2 and level 3*

The above test results show that most of the test results accord with level 2 reliability > Level 3 reliability under the same latency requirements. (Note: there are a few groups of anomalies caused by test errors)

According to the results corresponding to different latency requirements, if the users are distributed in excellent RSRP points and good RSRP points, under the latency requirement of 20 ms, the level 2 reliability can reach at least 99.9% (99.953%, 99.97%) and the level 3 reliability is only above 90% (97.167%); under the latency requirement of 50 ms, the level 2 reliability can reach more than 99.99% (100%) and the level 3 reliability is about 99% (98.973%).

- *Different reliability performance between different coverage conditions*

According to the results of different points, the reliability performance is not stable and is easily affected by the coverage conditions. Under the same latency requirement, the reliability performance of the good RSRP points and the excellent RSRP points is generally better than the average reliability performance obtained by the statistics of the whole cell. For example, under the latency requirement of 20ms, the average reliability of the whole cell of level 2 is about 90%~99%, and the reliability of good RSRP points and excellent RSRP points can reach 99.9%.

E. Results analysis and deployment recommendation

Corresponding reliability performance is different under different latency requirements. Overall level 2 is better than level 3 reliability performance. Different factories and different businesses have different requirements for latency and reliability, and the appropriate reliability level can be selected according to the specific needs of the factory. Typical industrial scenarios require about 20 ms of latency [4], in which case the reliability can be achieved by the industry is 99.9% at present. If the factory has deployed at 2.6G and requires 20 ms latency, 99.9% reliability performance, reliability level 2 configurations can be selected.

At the same time, the reliability performance is related to the coverage conditions. It is not possible to maintain the reliability performance of 99.9% with 20ms latency under any coverage conditions. There are still use cases, such as Differential Protection in electric power industry, or remote control of cranes in port, which require 99.999% reliability. More advanced solutions, for instance, low bit rate MCS/CQI table, slot repetition, and PDCP replication, are expected to future enhance reliability in 5G industrial networks.

IV. Rate Capacibility Evaluation

Unlike public network services focusing on the downlink rate,there is a universal desire of large uplink rate in industrial applications. In particular, typical industrial production scenarios have higher requirements for the uplink peak rate, such as factory machine visual quality inspection, the uplink rate of which in a single terminal can reach 1Gbps. Some scenarios with high terminal density also require lager uplink capacity, such as the remote operation of gantry cranes in harbour, the uplink capacity of which can reach more than 500Mbps [1]-[2]. To realize the large uplink quality of service in industrial production scenarios, it is important to clarify the rate distribution characteristics in a specific factory environment. In this paper, a method for evaluating the distribution relationship between rate and distance was proposed.

A. Simplified Relationship between Rate and Distance

The equation (1) show the relationship between the data rate R and the distance d. For simplicity, the rate R and the signal-to-noise ratio SNR follows Shannon Formula in [7].The cell signal strength decreases with the coverage radius index. In this paper, we focused on indoor scenes, in which interference is limited and was not considered in the formula. The relationship between the coverage radius d and the rate R is shown as follow:

$$R = Blog_2(1 + SNR) = Blog_2(1 + k/d^n) \quad (1)$$

where B is the bandwidth (Hz), *n* is the exponential power of *SNR*, and *k* is a constant. When *SNR* >> 1, the formula (1) can be simplified as:

$$R = Blog_2\left(\frac{k}{d^n}\right) \approx Blog_2 k - B \times nlog_2 d = a - blog_2 d \quad (2)$$

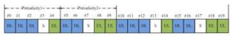
Where a and *b* are normal constants, which are related to environment and technology. Once the environment and other factors are determined, the values of *a* and *b* can be determined. Then the rate *R* of the position can be obtained by the distance *d*. Comparing the rate value by formula (2) with the actual rate requirement of the business, it is possible to quickly determine whether the network deployment can meet the business requirement.

B. Field Test Verification

- *Test Environment*

In 2020, NR small station test and verification was carried out in a factory in Hangzhou. The network environment parameters are shown in the Tab. 6 below.

Table 6. Rate trial conditions

Parameters	Value
Layout	Single pico site Indoor floor: 3000 m2
Inter-BS distance	25m
Carrier frequency	4.9 GHz,
Duplex mode	TDD
Frame structure	2.5ms dual TDD-UL-DL-Pattern，S:10:2:2 
UE Tx power	23dBm
BS antenna configurations	4 Tx/4 Rx antenna ports
BS antenna height	4 m
UE antenna configuration	2 Tx/4 Rx antenna ports
UE antenna height	1.5m
Total transmit power per TRxP	30 dBm (100 MHz)
Number of UEs per 3000m2	Single UE
Bandwidth	100 MHz
SCS	30 kHz
BLER	10%

- *Test Methods and results*

Test methods are as follows:

- In the process of test is from near end to far end, record the bit rate and distance of the point when the downloaded peak is stable at the optimal coverage point.
- Carry out the downlink TCP full buffer service at the selected test points with 5m interval. Each test point lasts for no less than 3 minutes. Record the distance, RSRP, SINR and rate of each point.

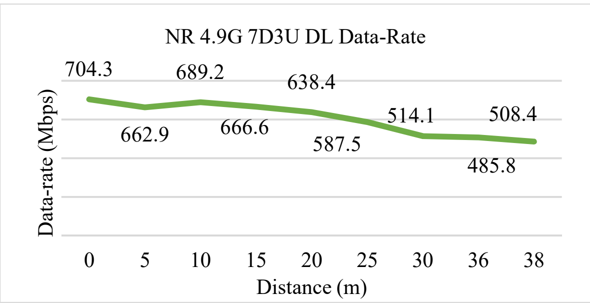


Figure 9. The relationship between rate and distance

- *Conclusions and deployment recommendation*

Based on the test measurement result as shown in Fig. 9, a is 1092.3 and b is 112.83. According to formula (2) and a, b, if the demand rate is 500 Mbps, the maximum LOS distance between the service and the base station is about 32 meters, which is consistent with the measured curve. Therefore, for this type of service, the deployment location needs to be about sight distance 32 meters from the base station. This method will greatly simplify the testing process, facilitate business requirements matching, and quickly realize network deployment in factories scenarios.

V. Conclusion

With its low latency, large bandwidth, and highly reliable network performance, 5G brings new opportunities for digital transformation of industrial sectors. To design 5G integrated Industrial Internet, we must first start from the current typical industry scenarios and needs, and clarify whether the network performance achieved by the existing 5G technology can meet different industrial needs. The evaluation methods, results, and recommendations put forward in this paper under the typical factory environment are expected to provide useful references for 5G adoption by industry sectors.

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