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Study of 3G/4G Network Convergence Planning Scheme in High-Speed Railway

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Abstract

This paper mainly introduces some related problems about special mobile communication signal based on TD-LTE and TD-SCDMA in high-speed railway, summaries the main difficulty of TD-LTE coverage in high-speed railway and analyses TD & LTE wireless network coverage characteristics and key technologies under the environment of high-speed railway. First, we make a contrast of the coverage range of TD&LTE uplink and downlink in ordinary and special situations. Then we consider effective cover radius, the distance and grazing angle between stations and railway in 2G/3G/4G networks, calculate different distance between stations. Last, we did capacity planning for TD & LTE as telephone traffic throughput required in high-speed railway. The result shows that distance between stations is limited by LTE on sharing station address. Using single RRH with two antennas, the antenna height is 30m, and the speed of the train is 250 KM/h, the RRH distance among different cells can be 1177 m, and the RRH distance among same cells can be 1311 m. In the tunnel scene, the leakage cable cover is used and the station space distance of TD & LTE is 0.5 km. Tunnel station should move the switch belt to outdoors as much as possible without switching. This paper finished the link budget, protection distance measurement of cells and study of coverage method in the tunnel scene. The result helps guiding in planning, designing and optimizing for high-speed railway network in reality.

Keywords

TD-LTE, Uplink and Downlink Coverage Range, Radio Remote Unit (RRU)

1. Introduction

As a future evolution direction of TD-SCDMA, TD-LTE has a lot of ascension in both data rate and system capacity compared with TD-SCDMA. The status of the long-term coexistence of GSM, TD-SCDMA and TD-LTE is the main way for our country in the next generation of wireless network. With the development of LTE, TD-LTE communication technology presents a good prospect in railway communication system. But when the train's speed is above 200 km/h, Doppler frequency shift, selection and re-election of the cell, shift, and penetration loss have a great effect on the network coverage. It is important for the development and construction of the high-speed railway to figure out how to use the present 2G/3G network to realize multi-network convergence, satisfy the signal quality requirement of the information transportation of the passenger railway line, guarantee the signal quality, reduce the probability of talk off, and meet the needs of clients' data volume. At present, high-speed railway signal transport has the following problems.

For the characteristics of high closing in compartment of high-speed train, the train has a high penetration loss of wireless signal [1]. Different types of the trains have different penetration loss. For example, the loss of Bombardier train is 24 dB. New fully enclosed trains have 5 - 10 dB more penetration loss than normal trains [2].

Fast moving of the high-speed railway causes the fading process of signal. The new cell should be switched quickly. It only takes seconds for high-speed trains to pass hundreds of coverage range. In this high-speed situation, it is easily to appear out-of-service and fail to selection cell etc. So the setting of the cell switch area is mainly related to the running speed of the trains, cell re-election and switch time for cells. It must be enough overlapping coverage area for two adjacent cells to meet the needs of the switch time for terminals when fast moving.

Common scene: including urban, suburban, and rural scene. This kind of scene usually has open spaces and route in chain structure.

Tunnel scene: this kind of scene has narrow and enclosed space. Wireless transmission environments are complex and the device installation conditions are strict.

Bridge scene: this kind of scene has open transmission environments in the bridge. It is hard to choose station address, and engineering condition is very limited.

Station scene: this kind of scene has big business volume, and the key point is to consider the switch rule and corresponding relationship and guarantee the successful switch of public net and special net [3].

2. Analysis of TD and LTE Signal Coverage and Link Budget in High-Speed Railway

Link budget is an important means for mobile communication network coverage analysis, and it is widely used in network planning, optimizing, operation and maintenance. There are many experience models in wireless communication models, but most of them are based on the universal model of COST231-Hata model [4]. COST231-Hata modified model is suitable for frequency range from

1500 - 200 MHz and it can be used in forecast of pass loss of TD & LTE. The empirical formula of COST231-Hata modified model is:

$$\begin{aligned} L(dB) &= 46.3 + 33.9\log f_c - 13.82\log h_{te} - \alpha(h_{re}) \\ &+ (44.9 - 6.55\log h_{te})\log d + CM \end{aligned} \tag{1}$$

Among it $f_c(MHZ)$ stands for working frequency.

$h_{te}(m)$: effective height of base station antenna, defined as the different between the real height of base station antenna and the average elevation of ground above mean sea-level among the antenna transmission range.

$h_{re}(m)$: effective height of terminal, defined as the height above ground level of the terminal antenna.

$d(km)$: the horizontal distance between antenna of base station and terminal.

CM: big city central correction factor

$\alpha(h_{re})$: effective modified factor of antenna. It is the function of size of coverage area, and its value is related to its wireless environment.

$$a(h_{re}) = \begin{cases} (1.11\lg f_c - 0.7)\ h_{re} - (1.56\lg f_c - 0.8)\ \textit{small and medium cities} \\ \begin{cases} 8.29(\lg 1.54 h_{re})^2 - 1.1 (f_c \le 300MHz) \\ 3.2(\lg 11.75 h_{re})^2 - 4.97 (f_c > 300MHz) \end{cases} \textit{big cities, suburban rural} \end{cases} \tag{2}$$

2.1. Study of Link Budget and Coverage Distance of TD-SCDMA in Ordinary Scene in High-Speed Railway

It is using COST231-Hata suburban model for TD-SCDMA in high-speed railway. Let's set CM to 24, and business 64 Kbit/s, and use antenna of two sectors, consider downlink in the train to RSCP > −90 dbm. **Table 1** shows the result of coverage distance of uplink and downlink with different height of antenna.

From the link budget, uses suburban model, when biggest uplink permitted path loss is 121 dB, the antenna height of terminal MS is 1.5 m, and the antenna heights of base station BTS are 30 m, 20 m and 10 m, the coverage distances of TD are 1590 m, 1381 m and 1107 m in ordinary scene in high-speed railway. At the same time, when the biggest downlink permitted path loss is 111 dB, the antenna height of terminal MS is 1.5 m, the antenna heights of base station BTS are 30 m, 20 m and 10 m, the coverage distances of TD are 938 m, 828 m and 682 m. Initial conclusion, TD uplink coverage is limited. Initial conclusion: TD uplink coverage is limited, and uplink coverage distance is considered as key point.

Table 1. Different uplink and downlink cell coverage distance of antenna length of TD-SCDMA.

Deployment Class	Uplink DPCH			Downlink RSRP > −90 dbm		
Maximum Allowable Path Loss (dB)	121.66			110.80		
MS Antenna Height (m)	1.50			1.50		
BTS Antenna Height (m)	30	20	10	30	20	10
Cell Range (km)	1.59	1.38	1.11	0.94	0.83	0.68

2.2. Study of Link Budget and Coverage Distance of TD-LTE in Ordinary Scene in High-Speed Railway

It is using COST231-Hata suburban model for LTE. Let's set CM to −24, the ratio of sub-frame as 3:1, the special ratio of sub-frame as 3:9:2, downlink speed as 4096 Kbit/s, uplink speed 256 Kbit/s for business and use F sector.

Table 2 shows the result of coverage distance of uplink and downlink with different height of antenna.

From the link budget, $\alpha(h_{re})$ uses suburban model, when biggest uplink permitted path loss is 113 dB, the antenna height of terminal MS is 1.5 m, and the antenna heights of base station BTS are 30 m, 20 m and 10 m, the coverage distances of LTE are 1012 m, 867 m and 730 m in ordinary scene in high-speed railway. At the same time, when the biggest downlink permitted path loss is 110 dB, the antenna height of terminal MS is 1.5 m, the antenna heights of base station BTS are 30 m, 20 m and 10 m, the coverage distances of TD are 851 m, 754 m and 624 m. Initial conclusion, TD uplink coverage is limited. Initial conclusion: LTE uplink coverage is limited, and uplink coverage distance is considered as key point.

2.3. Study of Link Budget and Coverage Distance of TD-LTE in Tunnel Scene in High-Speed Railway

It is enclosed in tunnel scene in high-speed railway, so that it's hard using outside signal other than signal penetration in tunnel portal. Outside environment influences little for inside coverage. Users in tunnel usually use network indoors so it's unnecessary to take users outdoors into consideration. The solution should be different for different tunnel [5].

Figure 1 is the signal coverage schematic of short tunnel. It is common in short tunnel scene. It is mainly installing RRU in both sides outside tunnel with high-gain panel antenna, and signal emission direction is inside the tunnel to cover tunnel. The realistic coverage length in tunnel is related to cross sectional area, construction materials and other factors. When setting the switching cell, tunnel portal is the bound, set it outside the tunnel, and set the same PN in the physics cells in and out the tunnel.

It is more complicated for long tunnel than short tunnel. It is decided by actual length and shape of the tunnel. **Figure 2** is the signal coverage schematic of

Table 2. Different uplink and downlink cell coverage distance of antenna length of TD-LTE.

Deployment Class	Uplink (pusch) edge rate 256 Kbps			Downlink RSRP > −110 db edge rate 4096 kbps		
Maximum Allowable Path Loss (dB)	113.18			110.00		
MS Antenna Height (m)	1.50			1.50		
BTS Antenna Height (m)	30	20	10	30	20	10
Cell Range (km)	1.01	0.87	0.73	0.85	0.75	0.62

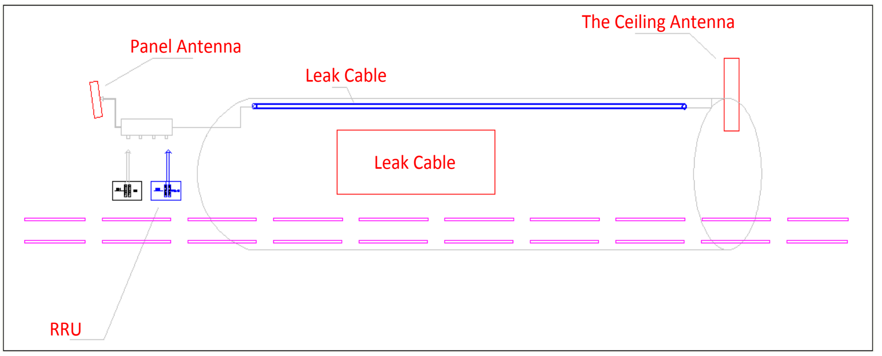

Figure 1. The signal coverage schematic of short tunnel.

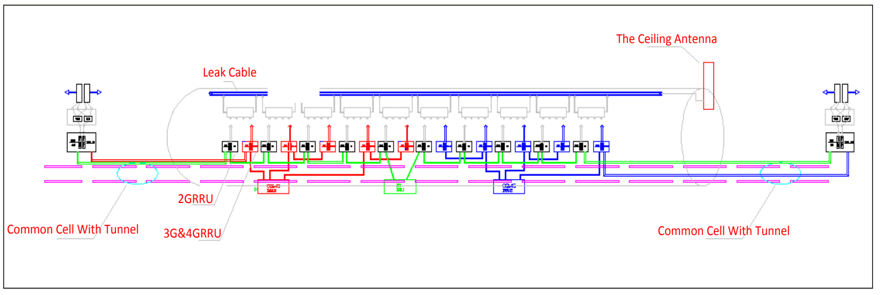

Figure 2. The signal coverage schematic of long tunnel.

long tunnel. It is common when using high-gain antenna outside the tunnel to cover inside tunnel, fiber-optic repeater and leak cable to cover inside the tunnel, distributed base station to connect several common antennas installed inside tunnel, and distributed base station to connect leak cable inside tunnel and add antenna covering the tunnel portal at the end of leak cable when out the tunnel. Because of possible existence of big bending in long tunnel and huge current of air when the high-speed train is running inside tunnel, the propagation model for train running in long tunnel is still exploring. When making the budget for long tunnel, leak cable coverage link budget is important. Consideration should include installing place for leak cable, loss value every 100 meters for leak cable, opening positions for leaking, tunnel width factor, coupling loss for passive device, and other factors [6].

Figure 3 is the signal coverage schematic of continuous tunnel. For continuous tunnel, coverage scheme is using RRU sharing cells, antenna at the top and leak cable. Take inside and outside the tunnel as one cell and decrease the switching times. Signal source base station offers coverage inside the tunnel, and also outside the tunnel, which can reduce the amount of base stations. During the intervals of the tunnels, the portal is covered by oriented planar antenna to keep the signal strength and take inside and outside the tunnel as one cell [7].

In tunnel scene, it takes leak cable coverage, and device is installed in refuge hole at the tunnel portal or inside the tunnel.

One of the RRU of TD & LTE is connected to POI. And POI is separated connecting to leak cable considering overlapping coverage. The station space of TD&LTE is 0.5 km. Tunnel station should move the switch belt to outdoors as much as possible without switching. **Table 3** and **Table 4** are the relation between uplink/downlink maximum space path loss of TD & LTE and RRU covering radius. Here the downlink speed is 4096 Kbps, uplink speed is 256 Kbps, and calculated with 521 m RRU covering radius. Tunnel scene is different with other scenes. If taken leak cable to network, covering is limited to LTE according to **Table 4**, and the RRU covering radius is 521 m.

3. Capacity Planning for TD & LTE

3.1. Capacity Planning for TD-SCDMA

If terminal penetration rate of TD-SCDMA is 22%, the amount of the TD phone users is 528; penetration of data card users is 2.5%, and the amount of the 3G

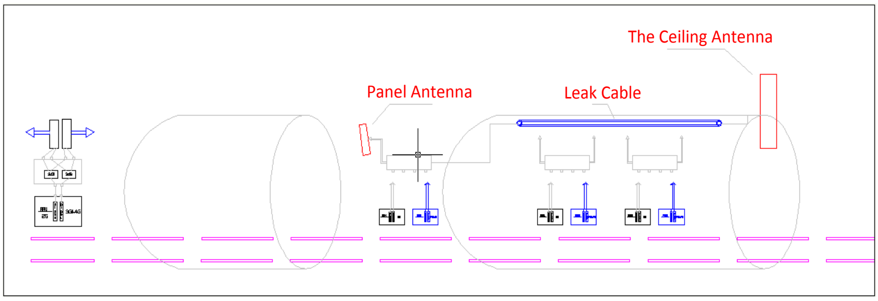

Figure 3. The signal coverage schematic of continuous tunnel.

Table 3. TD-SCDMA uplink/downlink maximum space path loss and RRU covering radius.

	TD_RSCP > −90 dbm	TD_DL (PDSCH)	TD_DL_CS 12.2k
Leak Cable Loss Every Meter (dB)	0.0453	0.0453	0.0453
Leak Cable Coupling Loss (dB)	65	65	65
Margin for Leak Cable Coupling Loss (dB)	5	5	5
Protection Margin (dB)	0	0	0
Shunting Loss (dB)	0	0	0
POI Loss (dB)	3.3	3.3	3.3
Jumper, Slice Loss (dB)	0.5	0.5	0.5
Penetration Loss (dB)	24	24	24
Fading Protection Loss (dB)	6.2	6.2	6.2
Body Loss (dB)	0	0	0
Interference Margin (dB)	3	3	3
Storage Total (dB)	107	107	107
Allowable Path Loss (db)	19	29	31.08
RRU Covering Radius (m)	419	640	686
Total Allowable Loss (dB)	126	136	138
Receiver Sensitivity (dB)		−100	−112
Required Power in Train (db)	-90		
Transmitting Power (dBm)	36	36	26

Table 4. TD-LTE uplink/downlink maximum space path loss and RRU covering radius.

	LTE_DL_RSRP >−110 dbm	LTE_DL (4M)	TD_UL_CS 12.2 k	LTE_UL (256 kbps)
Leak Cable Loss Every Meter (dB)	0.042	0.042	0.0453	0.042
Leak Cable Coupling Loss (dB)	67	67	65	67
Margin for Leak Cable Coupling Loss (dB)	5	5	5	5
Protection Margin (dB)	0	0	0	0
Shunting Loss (dB)	0	0	0	0
POI Loss (dB)	3.3	3.3	3.3	3.3
Jumper, Slice Loss (dB)	0.5	0.5	0.5	0.5
Penetration Loss (dB)	24	24	24	24
Fading Protection Loss (dB)	6.2	6.2	6.2	6.2
Body Loss (dB)	0	0	0	0
Interference Margin (dB)	3	3	3	3
Storage Total (dB)	109	109	107	109
Allowable Path Loss (db)	16.2	25.04	31.86	19.38
RRU Covering Radius (m)	386	596	703	461
Total Allowable Loss (dB)	125	134	138	128
Receiver Sensitivity (dB)		−94	−118	−105
Required Power in Train (db)	−110			
Transmitting Power (dBm)	15	40	21	23

data card users is 60. Carrier traffic of R4 when line area is busy: total uplink traffic is 20.5332 Erl, and total downlink traffic is 42.2232 Erl. Loading planning is 75%, and uplink/downlink is calculated separately. To meet the traffic requirement of bigger traffic capacity, line area needs 4 R4 carriers. Carrier traffic of HS when line area is busy: uplink traffic averagely is 67.2 kbps, and downlink traffic averagely is 504 kbs. Bandwidth of every HS carrier is 504 k, and it takes 2 HSPA carriers. So, high-speed railway line area needs 6 carriers, which 4 of them is R4 carrier, and 2 of them is HSPA carriers.

3.2. Capacity Planning for TD-LTE

Single user traffic according to the statistic model: downlink is 22.75, and uplink is 5.29 (according to experience of the LTE FDD large-scale commercial website). If the train is full loading, the penetration rate of China Mobile users is 70%, and penetration of LTE terminals is 80%, then the amount of single train terminal users is: 1200 * 70% * 80% = 672. According to the single user requirement and user scale, it can do the throughput rate estimating to each user. We get peak demand of the throughput rate of the train is (two-way):

Downlink: 22.75 * 672 * 2 = 30.58 Mbps

Uplink: 5.29 * 672 * 2 = 7.14 Mbps

So, bandwidth of 20 M can meet the capacity requirement in the number of users.

4. Station Spacing Setting in Standards of 3G/4G and Different Speeds

Considering that the key point of later GSM, TD-SCDMA and TD-LTE sharing the same address is setting reasonable station space to satisfy the requirements of the setting of the logical cells of the three networks, we suggest the setting of the each cell brings into correspondence with switching point to bring convenience to network planning and optimizing [8]. Through the investigation and research on the industries, the devices of TD-SCDMA and TD-LTE both use single RRH with two antennas and they have comparative networking capability to satisfy the corresponding requirement of the cell. After overall consideration of the effective coverage radius of the three networks, distance from station to railway, grazing angle and other factors, station space = 2 * (coverage ratius^2 − station to railwaydistance^2)$^{1/2}$ − overlapping coverage distance. The distance between station and railway track is 100 meters. The station spaces in different standards and speed are in the following **Tables 5-9**.

5. Conclusion

By **Table 3** and **Table 4**, station spacing is limited to LTE on sharing the station address. After overall consideration, we suggest use single RRH with two antennas when the antenna height is 30 m, and the speed of the train is 250 KM/h, the

Table 5. Station space of LTE by uplink.

BTS Antenna Height (m)		30	20	10
Uplink	Single RRH Coverage Distance (m)	830	717	630
	Two RRH Distance of Different Cells (m) (200 km/h)	140	1173	997
	Two RRH Distance of Different Cells (m) (250 km/h)	1390	1162	986
	Two RRH Distance of Different Cells (m) (300 km/h)	1378	1150	974
	Two RRH Distance in same Cells (m) (200 km/h)	1521	1295	1121

Table 6. Station space of LTE by downlink.

Downlink RSRP > −110 dbm	Single RRH Coverage Distance (m)	725	646	539
	Two RRH Distance of Different Cells (m) (200 km/h)	1189	1029	813
	Two RRH Distance of Different Cells (m) (250 km/h)	1178	1018	801
	Two RRH Distance of Different Cells (m) (300 km/h)	1166	1006	789
	Two RRH Distance in same Cells (m) (200 km/h)	1311	1153	939

Table 7. Station space 2 G by downlink

BTS Antenna Height (m)		30	20	10
Downlink & RXLEV > −90 db	Single RRH Coverage Distance (m)	1081	1061	1029
	Two RRH Distance of Different Cells (m) (200 km/h)	1597	1557	1492
	Two RRH Distance of Different Cells (m) (250 km/h)	1438	1458	1353
	Two RRH Distance of Different Cells (m) (300 km/h)	1318	1278	1214
	Two RRH Distance in same Cells (m) (200 km/h)	2023	1983	1919

Table 8. Station space of TD-SCDMA by uplink.

BTS Antenna Height (m)		30	20	10
Uplink	Single RRH Coverage Distance (m)	1354	1182	956
	Two RRH Distance of Different Cells (m) (200 km/h)	2434	2089	1635
	Two RRH Distance of Different Cells (m) (250 km/h)	2392	2047	1593
	Two RRH Distance of Different Cells (m) (300 km/h)	2351	2006	1552
	Two RRH Distance in same Cells (m) (200 km/h)	2569	2225	1773

Table 9. Station space of TD-SCDMA by downlink.

Downlink RSRP > −90 dbm	Two RRH Distance of Different Cells (m) (200 km/h)	1319	1137	892
	Two RRH Distance of Different Cells (250 km/h)	1277	1095	851
	Two RRH Distance of Different Cells (m) (300 km/h)	1235	1054	809
	Two RRH Distance in same Cells (m) (200 km/h)	1459	1279	1037

RRH distance among different cells can be 1177 m, and the RRH distance among same cells can be 1311 m. Railway is outdoor coverage. TD & LTE use single RRH with two antennas. When do the specific planning, put further distance RRH into the same cell, and plan the cell switch area in the area of the close two RRH stations. For assistance of double RRH with two antennas, plan the poor coverage area.

In tunnel scene, it takes leak cable coverage, and device is installed in refuge hole at the tunnel portal or inside the tunnel. One of the RRU of TD & LTE is connected to POI. And POI is separated connecting to leak cable considering overlapping coverage. The station space of TD & LTE is 0.5 km. Tunnel station should move the switch belt to outdoors as much as possible without switching.

The scheme is based on theoretical calculation. The solution for multi-network convergence in high-speed railway is a new subject, and specific data need be calculated in real situation. The result should be confirmed in actual scene, and all theoretical data takes as reference.

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