In-building commercial mobile telecommunication system design for mass rapid transit station

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Abstract: The mobile telecommunication system provides voice, data and video communications between stations, Operation Control Centers, depots and all necessary areas and facilities. The Preliminary Design is an overall system design that elaborates on the proposed system configuration with an emphasis on how the interface requirements are to be achieved. The contractor verified the preliminary design for the coverage of the wireless access network with respect to the General Specification (GS) and Particular Specification (PS) of the mobile telecommunication system. The mobile service provider (Telco) should ensure that the mobile network coverage in Mass Rapid Transit tunnels and underground stations provide 95% coverage for all the defined areas. The Telco should ensure seamless handover success rate > 98% and proposed the required overlap distance in between the antennas. Based on the design assumption made on the link budget, the indoor system design to be aligned within 15m radius coverage, which will contribute to distance in between antennas will be at 30m horizontal distance. This placement can be varied within 10-15% and subject to line of sight, physical obstruction or fixing constraint at side.

1. Introduction

Long Term Evolution (LTE) is the 4th generation telecommunication mobile network standard that developed by 3rd Generation Partnership Project (3GPP). LTE provides higher throughput and coverage compared to the previous mobile networks. A lot of researches have been carried out to improve the LTE network performance through various scheduling algorithms. A survey is conducted in [1] to study the heterogeneous network that consists of Femto, Pico and macro cells in order to support the dense indoor usages. Analysis of the LTE network planning in [2] and [3] for the indoor building in order to enhance the indoor coverage. The deployment of the Femto cell in the indoor mobile network is out of the professional control, since these cells are deployed by the users. This will contribute to a high interference between the various cells that operated under the same spectrum [4]. The practical aspects of the LTE network design are reported in [5]. The LTE coverage and link budget computation are reported. However, the computation of the indoor network is not included in this work. Extra works are urgently needed to further improve the planning of the indoor mobile telecommunication system, especially for the Mass Rapid Transit Station that involve buildings and tunnels.

The mobile telecommunication system is to provide voice, data and video communications between stations, Operation Control Centers, depots and all necessary areas and facilities. The mobile telecommunication system is designed to facilitate normal train and station operation, management of incidents, abnormal operations and emergencies.

The Preliminary Design is an overall mobile telecommunication system design that elaborates on the proposed system configuration with an emphasis on how the interface requirements are to be
achieved. The design also identifies the function of each system, subsystem, equipment or other elements within the overall design and specifies the relationships and interfaces between each element of the system, including the system for interfacing with other work contractors.

In accordance with the General Specifications (GS) for Systems Contracts, the design processes comprise of Conceptual Design, Preliminary Design and Final Design. Each design stage requires the contractor to produce a stage design document for acceptance by the Telco. The acceptance of the stage of design allows the contractor to proceed with the next stage of design. The contractor verified the preliminary design for the coverage of the wireless access network with respect to the General Specification (GS) and Particular Specification (PS) of the mobile telecommunication system.

The design verification approach is consisted of the following. (1) Set up the verification baseline with PS documents relating to coverage specification. (2) Define the preliminary design for the intended coverage area. (3) Clarify the design input parameters. (4) Verify the simulation via IBWave against the coverage specification of the PS documents. (5) Finalize the findings of the design verifications.

2. Mobile Network Coverage Planning for Mass Rapid Transit Station

The Telco should ensure that the mobile network coverage in the mass rapid transit tunnel and underground stations should provide 95% coverage for all the defined areas, i.e. inside the tunnel, inside the mass rapid transit carriage, concourse paid area, concourse unpaid area (ticket counter/ticketing machines), platform, lift lobby, escalators, passageways, entrances, public area, stair, inside the public lift, toilet, prayer and ablution rooms.

The Telco should ensure seamless handover success rate > 98% and proposed the required overlap distance in between the antennas with calculated justifications. The handover process is expected in the following areas, i.e. tunnel sector, station sector, between different section inside the tunnel, between tunnel sector and outdoor sector at tunnel entrance and exit.

A common Distributed Antenna System (DAS) is used to provide a radio frequency (RF) distribution infrastructure inside the stations, noise barriers and along the tunnel sections of the mass rapid transit line. The DAS is used to extend the signal coverage of the commercial mobile phone operators including but not limited to 2G, 3G, 4G frequency division duplex (FDD) and 4G time division duplex (TDD) services. The common DAS shall support public mobile phone services including GSM900, GSM1800, WCDMA900, WCDMA2100, LTE-FDD and LTE-TDD for both voice and data communication. The DAS shall carry signals of all the specified networks and shall also support the Multiple-in-Multiple-out (MIMO) feature of LTE FDD. The DAS shall consist of not less than three separate RF transmission elements to provide the coverage. One of the transmission elements shall carry a set of LTE FDD signals in duplex mode to support the corresponding MIMO feature. The RF transmission elements shall comprise of antennas and radiating cable distribution systems. A donor antenna system or equivalent is required to assure the Telco services inside the noise barrier and short tunnels of the rapid transit line are good. Point of Interconnection (POI) shall be provided in the Common Telecommunication Equipment Room (CTER) located at each mass rapid transit station.

In order to ensure that the commercial mobile telecommunication system does not interfere with the wireless distributed communication system, the Telco will compute the link loss calculations to demonstrate that the coverage of each section of the mass rapid transit line meets the required performance levels. The link loss budget calculation shall consider the following factors:

- Insertion loss for passive devices;
- Gain for antennas;
- Gain/noise figure/intermodulation intercept for active devices;
• Cable attenuation and coupling loss;
• Transmit power;
• Minimum reception level;
• Reception probability;
• Attenuation due to reception distance;
• Fading margin;
• Increase in noise level due to use of the remote unit (RU);
• Main unit (MU)/RU system noise figure;
• Difference between Common Pilot Channel (CPICH) and carrier power;
• Drop in power per carrier in the downlink RU due to more than one carrier;
• Train shielding loss;
• Body loss and loss due to passenger crowd, particularly in train cabin and platform;
• Increase in radiating cable coupling loss due to reception distance;
• Miscellaneous losses like connector loss;
• Carrier-to-noise/interference ratio; and
• Degradation in connector loss due to normal wear and tear for its design life.

The Telco shall demonstrate and evaluate the system performance and measure continuously along the areas and routes where passengers may reasonably be expected to occupy or traverse. The radio coverage is measured by a dipole with 0dB gain and 50Ω impedance, vertical orientation at 1.2m above the floor level and continuous free from the body and crowd losses for 95% of locations and 95% of time in the measured areas.

A walk test is undertaken inside the stations and link-ways, for any given continuous 40m path, the result shall be a minimum 95% of the specified requirements. A walk test is undertaken on the train running in tunnels and the noise barrier sections connecting to the portal of the tunnels, for any given continuous 225m train path. The results shall be a minimum of 95% of the specified requirements.

The measurement path shall also meet the following conditions:
• While the train is running at the maximum speed; and
• Measured at the centreline of the train saloon with full passenger loading.

All power dividers and couplers shall have an operating frequency range from 800MHz to 2690MHz and an insertion loss less than 1dB. For the RF Distributed Antenna System (DAS), the downlink (DL) coverage for 95% of location and 95% of the time. For the RF Distributed Antenna System (DAS), the uplink (UL) coverage for 95% of location and 95% of the time. The uplink design shall allow a dynamic range better than 60dB for the uplink signal, with maximum signal reaching -35dBm under normal operating conditions.

The coverage in the tunnel shall include handover zone design between different sectors to allow worst-case handover zone of 10s for GSM, 6s for WCDMA and 6s for LTE FDD with reference to the trainspeed at normal operation. The signal strength shall conform to the requirements in the above paragraphs. The uplink design shall allow a dynamic range better than 60dB for the uplink signal. All power dividers and couplers shall have an operating frequency range from 800MHz to 2690MHz and an insertion loss less than 1dB.

The design verification assumptions are as follows, i.e. the short tunnel and noise barrier shall be verified upon design available. The handover duration is set as 10 seconds at 100km/hour or 277m in the tunnel inter sector. The station environment is assumed as an open space area within a building.
3. Link Budget Planning for Mass Rapid Transit Station A

The link budget planning is carried out for Mass Rapid Transit Station A. The LTE design refers to a composite power value of 20W instead of Reference Signals Received Power value. Hence the Equivalent Isotropically Radiated Power value shown in Link Budget table for LTE system is not referring to Reference Signals Received Power value. The loss according to the number of carriers using the system was not calculated in the link budget. Hence, it does not reflect the actual loss of the system. The calculation and antenna system designed is for indoor system, hence the indoor penetration loss can be ignored. The “Required distance” value used is 15m for the antenna placement defined in the Mass Rapid Transit Station A. The cable routing of the Mass Rapid Transit Station A is shown in Figure 1. The cable routing is in perpendicular to building alignment for two runs of cable at platform level. Adjustment is needed during the cable installation process.

The loss reference per meter for Cellflex 1 ¼” Coaxial cable per meter for respective frequency usage is shown in Table 1. Other losses calculation and connection link were viewed as in place inclusive with input parameter for each path is already taking into consideration of Reference Signals Received Power and multiple number of carrier losses. Minor inaccuracy was noticed, however, with the make good of that, it will further improve the Equivalent Isotropically Radiated Power (EIRP) output at the antenna.

Lift at concourse level is within the non-intended coverage area. The lift shall be out of the coverage area as per defined intended coverage area. Antenna placement found located within 20m-30m distance in between each antenna location. This value is aligned in the link budget calculation. The colour legend used for the signal strength reference is decoded to colour code. It is used by the Telco for coverage evaluation. The colour code used is shown in Figure 2. The colour review and coverage verification are carried out based on the Reference Signals Received Power signal strength. The verification refers to the Reference Signals Received Power value of LTE mobile network design instead of referring to the composite output power of Remote Unit. Table 2 shown the downlink link budget calculation for all wireless mobile technologies deployed inside the underground Mass Rapid Transit Station A.

| Frequency (MHz) | Attenuation (dB/100m) | Attenuation (dB/100ft) | Power (kW) |
|----------------|-----------------------|------------------------|------------|
| 800            | 2.47                  | 0.752                  | 4.45       |
| 824            | 2.51                  | 0.764                  | 4.38       |
| 894            | 2.62                  | 0.799                  | 4.20       |
| 900            | 2.63                  | 0.802                  | 4.18       |
| 925            | 2.67                  | 0.815                  | 4.12       |
| 960            | 2.73                  | 0.831                  | 4.03       |
| 1500           | 3.50                  | 1.07                   | 3.14       |
| 1900           | 4.00                  | 1.22                   | 2.75       |
| 2100           | 4.24                  | 1.29                   | 2.59       |
| 2200           | 4.35                  | 1.33                   | 2.53       |
| 2500           | 4.69                  | 1.43                   | 2.34       |
| 2600           | 4.80                  | 1.46                   | 2.29       |
| 2700           | 4.90                  | 1.49                   | 2.24       |
Figure 1. Mass Rapid Transit Station A.

Figure 2. The colour code used in this project.

Table 2. Downlink Budget Table for Mass Rapid Transit Station A

| Wireless Mobile Technologies | LTE | GSM | GSM | LTE | WCDMA | LTE | LTE |
|-----------------------------|-----|-----|-----|-----|--------|-----|-----|
| Centre Frequency, MHz       | 850 | 915 | 1880| 1880| 2170   | 2300| 2655|
| Lamda (λ), m                | 0.35| 0.33| 0.16| 0.16| 3.00   | 0.13| 0.11|
| Channel Bandwidth, MHz      | 10  | 10  | 10  | 10  | 15     | 10  | 10  |
| Carriers                    | 2   | 4   | 4   | 4   | 12     | 3   | 7   |
| Transmitter - eNodeB        |     |     |     |     |        |     |     |
| Base Station Transmit Power, dBm | 43.0 | 43.0 | 43.0 | 43.0 | 43.0   | 43.0| 43.0|
| Common Pilot Channel (CPICH) (10%), dBm | - | - | - | - | 33.0 | - | - |
| 71-20 Band Combiner Loss, dB | 4.9 | 4.9 | 4.3 | 4.3 | 4.3    | 6.0 | 6.0 |
| Total DAS Loss (Components Feeder), dB | 30.0 | 30.0 | 25.0 | 25.0 | 30.0   | 35.0| 35.0|
| Antenna gain, dBi            | 3.4 | 3.4 | 5.9 | 5.9 | 5.9    | 5.9 | 5.7 |
| Equivalent Isotopically Radiated Power (EIRP), dBm | 11.5 | 11.5 | 19.6 | 19.6 | 4.6    | 7.9 | 7.7 |

The actual Common Pilot Channel and Reference Signals Received Power values of 3G and 4G corresponding to the number of carriers that will be used in the Mass Rapid Transit Station A are used as references. The output power per carrier of the remote unit specification is shown in Table 3. The ‘Building Penetration Loss’ is removed from the total loss calculation. Total DAS loss and Combiner loss value are split in the link budget calculation. The link budget calculation is updated to reflect the actual scenario consideration. The link budget calculation is revised to align design criteria in order to achieve the positive value of ‘Excess Margin’. The EIRP output of the antennas is set to be within the target value set at link budget (less than 3dBm variance).
Table 3. The output power per carrier of the remote unit for forward path (downlink)

| No. of Carriers | Universal Mobile Telecommunications | LTE, dBm |
|-----------------|------------------------------------|----------|
| 1               | 43                                 | 43       |
| 2               | 40                                 | 40       |
| 4               | 37                                 | 37       |
| 8               | 34                                 | 34       |

Based on the design assumption made on the link budget, the indoor system design to be aligned within 15m radius coverage, which will contribute to distance in between antennas will be at 30m horizontal distance. This placement can be varied within 10-15% and subject to line of sight, physical obstruction or fixing constraint at side.

4. Conclusion

The link budget planning is carried out for Mass Rapid Transit Station A. The LTE design refers to a composite power value of 20W instead of Reference Signals Received Power value. The calculation and antenna system designed is for an indoor Mass Rapid Transit Station. The indoor system design of the Mass Rapid Transit Station A is aligned within 15m radius coverage, which will contribute to the distance in between antennas will be at 30m horizontal distance. The system designed consists of downlink (DL) coverage for 95% of the location and 95% of the time. The mobile telecommunication system for Mass Rapid Transit Station A meets all the GS and PS requirements.

References

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