2G, 3G Network Planning and Optimization...

Archives

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2.11 Tunnel Coverage

2.11.1 Characteristic of Tunnel Coverage

At present, most of the tunnels are dead zones, so you must make out special solutions for tunnel coverage. The tunnel types include railway tunnel, highroad tunnel, and underground railway tunnel. Each tunnel has its characteristics, and they are specified as follows.
For the highroad tunnel, it is wide. The coverage in the highroad tunnels is relatively stable. When there are vehicles passing by, you can select the antennas with a larger size to obtain a higher gain, so the coverage distance is larger.
For the railway tunnel, it is narrow, especially when there is a train passing by; only a little room is left in the tunnel, so the radio propagation is greatly affected. Moreover, the train has great effect on radio signals. Since the antenna installation room is quite limited, the antenna size and gain are greatly restricted. In addition, because general cars cannot be driven to such tunnels, the tunnel coverage is hard to be tested. Therefore, the planning for highroad coverage is different from that of the railway coverage.
The length of tunnels ranges from several hundred meters to several kilometers. For short tunnels, you can adopt flexible and economical means to realize the coverage. For example, you can install a general antenna near one end of the tunnel, with the radiation directed to the inside. For long tunnels, however, you must adopt other means. Actually, the coverage solution varies with tunnels, so it is designed according to actual conditions.
Cross section of the single-track railway tunnel and multi-track railway tunnel: The smaller the area of the cross section, the greater the loss when a train passes through the tunnel. The related calculation and analysis are based on the multi-track railway tunnels and highroad tunnels. For the calculation and analysis for single-track tunnels, the protection margin can be 5 dB greater than that of multi-track railway tunnels.

Before planning tunnel coverage, you must prepare for the following data:
Length of the tunnel
Width of the tunnel
Number of tunnel holes (1 or 2)
Needed coverage probability (50%, 90%, 98% or 99%)
Structure of the tunnel (it is constructed with metals or concretes)
Number of needed carriers (1–30)
Minimum receiving level in the tunnel (generally, it ranges from -85 dBm to -102 dBm)
Distance between tunnel holes
Whether AC/DC is available
Whether the hole can be punched in the tunnel wall
Signal level at the tunnel entrance
Existed signal level in the tunnel

2.11.2 Tunnel Coverage Solution

I. Link budget
Indoor radio link loss is mainly decided by path loss medium value and shadow fading. A tunnel can be taken as a tube. The signals are transmitted through the reflection of walls and straight transmission, with straight transmission the major form. ITU-R suggests an indoor propagation model on page 1238, which is also effective for tunnel coverage. The formula is as follows:
Lpath = 20 lg f + 30 lg d + Lf (n) - 28 dB
Here,
"f" indicates frequency (MHz)
"d" indicates distance (m)
"Lf" indicates penetration loss factors between floors (dB)
"n" indicates the number of floors lying between the mobile station and antenna.
The Lf (n) can be neglected in tunnel coverage, so the following equation can be applied in the calculation of the radio propagation in tunnels. That is:
Lpath = 20 lgf + 30 lg d - 28 dB

II. GSM signal source selection
A GSM signal source and a set of distributed antenna system are a must for tunnel coverage. For tunnel coverage, the GSM signal source is selected according to the radio coverage, transmission, traffic, and the existing network equipments near the tunnel. A macro cell base station, a micro cell base station, or a repeater can work as a GSM signal source for the tunnel coverage.
For the coverage of railway tunnels and highroad tunnels, the indoor macro cell base station is seldom used as signal source, but it can be used for an underground railway which requires the coverage of platforms and entrances. In this case, the capacity of the signal source must be great. In most cases, however, the tunnel coverage is realized by micro cell signals.
For the areas to be covered, if the nearby network capacity is adequate, the capacity expansion is unnecessary. And if there are good GSM signals available, namely, the donor signal level meets the requirements of a repeater (for example, -70 dBm); a repeater can work as the signal source for the tunnel coverage. With the increase of traffic, however, you must use GSM base stations to replace the repeaters.
Adequate isolation must left between donor antenna and retransmission antenna, though it will cause difficulty in antenna installation. Generally, the log-periodical antenna with great front-to-back ratio is

used as the retransmission antenna.
The general antenna (wireless repeater), coaxial cable, and optical fiber (optical repeater) can connect a repeater to a donor cell.
For tunnel coverage, the installation space and auxiliary equipments are quite limited, so micro cell base stations and repeaters instead of macro cell base stations are often applied in tunnel coverage.
In mountain areas, repeaters are more likely used because strong signal level often exists at the mountain tops near the tunnel. In this case, the antenna isolation requirement can be easily met. If the signal level of the existed network near the tunnel is not strong enough, you can use a micro cell for the tunnel coverage.
III. Antenna feeder system selection
After deciding the GSM signal source, you must configure the antenna feeder system for the tunnel coverage according to actual conditions. Three types of configuration are available, namely, coaxial feeder passive distributed antenna, optical fiber feeder active distributed antenna, and leaky cable.
Hereunder introduces the tunnel coverage based on coaxial feeder passive distributed antenna and leaky cable.

2.11.3 Tunnel Coverage Based on Coaxial distributed antenna system

In a coaxial distributed antenna system, the following RF components are used:
Feeder (3/8", 1/2", or 7/8") and jumper
Power splitter
Power splitter
Antenna
This section introduces three tunnel coverage solutions based on the coaxial distributed antenna system.
I. Solution 1
Tunnel coverage solution based on the bi-directional passive distributed antenna system.
Tunnel coverage solution based on bi-directional passive distributed antenna system
According to this solution, if the needed minimum signal level is -85dBm (the location probability is 50%), you must add a margin of 8 dB if the want to enhance the location probability to 90%.
If the gain of the bi-directional antenna is 5 dBi, the loss of the equal probability power splitter and the jumper is 2 dB, and the feeder with the specification of 7/8" is used, the path loss in 100 meters is 4 dB and the output power of the equipment is 39 dBm.
Suppose that the level of the signals transmitted by the first bi-directional antenna is -85 dBm at the tunnel entrance, you can calculate the distance between the antenna and the tunnel entrance using the following equation:
Pout- Lpath (d) – Lcable (d) – Ljumper + Gant = -85dBm + 8dB90%_loc.Prob
Here,
Pout indicates the output power (39dBm).
Lpath (d) indicates the path loss from the first bi-directional antenna to the tunnel entrance.
Lcable (d) indicates the cable loss.
Ljumper indicates the jumper loss (2 × 2 dB).
Gant indicates the antenna gain (5 dBi).
If introducing the previous data to the equation, you can obtain the sum of the Lpath (d) and Lcable (d), that is, 117 dB.
For the relationship between distance “d” and Lpath (d) and Lcable (d), see Figure 5-34, in which the curve indicates Lpath (d) and the slant line indicates Lcable (d).
1 You can obtain that d = 301m through estimation.
If a power splitter is adopted for the first antenna, a loss of 3dB must be added. In this case, the sum of Lpath (d) and Lcable (d) is 114 dB.
2 You can also obtain that d = 261m through estimation.
For railway tunnels, train filling will affect signal propagation, so a protection margin of 5dB must be considered when the antenna is installed in the tunnel. In this case, d = 240m. That is, if a bi-directional antenna is installed in the tunnel, it can coverage a distance of 480m.
If a power splitter is adopted for the second antenna, the coverage distance between the first antenna and the second antenna will be shortened unless an amplifier is used.
The followings analyze the coverage when no amplifier is adopted for the second antenna.
The total power output by the first power splitter (it is installed at the first antenna) Pout1 is expressed as follows:
Pout1 = Pout – Lcable (d) - Ljumper - Lsplitter = 39dBm –Lcable (261m) - 2dB - 3dB= 23.56 dBm. (The cable loss in 261m is about 10.44 dB, jumper loss is 2 dB, and the power splitter intersection loss is 3dB).
Suppose the overlapping level between the two antennas is -85 dBm, the distance between the second antenna and the first antenna is: d2 = d + x. Here, “d” indicates the coverage distance of the first antenna (261m), and “x” indicates the coverage distance of the second antenna in the single direction.
According to the previous analysis, the following two equations can be obtained:
Pout1 – Lcable (261m) – Lcable (x) – Ljumper + Gant – Lpath (x) = - 85dBm + 8dB90%_loc.Prob
Lpath (x) + Lcable (x) = 108.56dB
Plus the two equations, you can obtain the value of x, that is, 100m. This means that when no amplifier is adopted, two antennas can coverage a tunnel distance of 722m, namely, 2*(261 + 100) m = 722m.
If you adopt cascaded antennas, the transmit power is relative low due to the coaxial cable loss. In this case, you can use the amplifier to amplify the power.
II. Solution 2
If a tunnel is not long, you can adopt a simpler coverage mode.
Tunnel coverage solution based on a single antenna
According to this solution, a directional antenna is installed at the tunnel entrance, with the radiation directed to the inside. The following analyze this coverage solution.
In this solution, Pout = 39 dBm (suppose that the output power of the GSM signal source is 8W).
If the Lpath (d) indicates propagation loss, the sum of Lcable (d) and Ljumper is 5dB, the antenna gain Gant is 8 dBi, and the needed received level is -77dBm, the Lpath (d) is expressed as follows:
Lpath (d) = 39dBm - 5dB + 8dBi – (-77dBm) = 119 dB
According to the equation Lpath (d) = 20 lg10f + 30 lg10d - 28 dB, the value of “d” can be obtained, that is, 858m.
The previous analysis is applicable to highroad tunnels. For railway tunnels, you can consider a margin of 10 dB due to the effect of train filling, but the coverage distance of the antenna in railway tunnels is calculated the same as that in highroad tunnels. According to the calculation, d = 398m.

2.11.4 Tunnel Coverage Based on Leaky Cable System

If adopting leaky cables to realize the tunnel coverage, you must find the specifications of the leaky cables and complete the leaky cable design according to the following steps:

1) Decide coverage factor
2) Calculate the gain of the bi-directional amplifier
3) Estimate the length of the leaky cable between the feeder source and the first amplifier
4) Estimate the length of the leaky cable between the amplifiers
5) Decide the number of needed amplifiers

The followings describe these steps in details.

I. Decide coverage factor

The following information is needed for deciding the coverage factor:

Coupler loss
Number of carriers
Coverage probability

Coverage factor indicates the loss in the areas 2 meters beyond the leaky cable (along the vertical direction). This loss includes the coupler loss of the leaky cable and protection margin required by the coverage probability. If 90% of coverage probability is required, you must add 8dB to the medium level. Some leaky cables specify the relationship between the coverage probability and coupler loss.
The coverage factor is determined by the parameters, such as coupler loss, RF carrier number, coverage probability, and tunnel type. For the decision of coverage factor in concreter tunnels. For the decision of coverage factor in metal tunnels. When deciding the coverage factor, you can fix a point in the graph and mark a horizontal line through this point, and this line intersects required coverage probability. This intersection point is the coverage factor.

Coverage factor in metal tunnels:

For example, if the leaky cable with a coupler loss of 71 (900 MHz) is used, the RF carrier number is 18, and the coverage probability is 90, the coverage factor in a concrete tunnel is -77

II. Decide cable length between GSM signal source and the first amplifier

Before deciding cable length between GSM source and the first amplifier, you must obtain the following information:

Transmit power of the signal source (dBm)
Jumper loss: 1 dB
Connector loss: 1 dB
Leaky cable loss: 2 dB
Transmit power at the feeder source (dBm)

When calculating the power at a point of the feeder, you must subtract the feeder propagation loss from the GSM signal source. If a wireless repeater with an output power of 18 dBm (18 carriers) is used as the GSM signal source, and the attenuation from the jumper to feeder, and from the feeder to the leaky cable is 7 dB (That is, the power from the repeater is transmitted from a jumper to a feeder, and then from the jumper to a leaky cable, so four connectors are needed. Generally, the attenuation is 2 dB for each jumper, 1 dB for each feeder, and 0.5 dB for each connector, so the total attenuation is 7 dB.), the transmit power at this point is 11 dB. For the connection of leaky cable.

Connection scheme of leaky cable:

Suppose the needed signal level in a tunnel is -85 dBm, the signal level at the first amplifier must be equal to or greater than -85 dBm. The coupler loss and longitudinal propagation loss of the leaky cable are present between the signal feeder point and the first amplifier. They are calculated according to the following equation:

LossLong = 11dBm – (-85dBm) + Losscoup. Here, Losscoup indicates the coverage factor, and it is -77dB when 90% coverage is ensured. Therefore, the LossLong is 19 dB (that is, 11dBm + 85dBm -77dB = 19dB).

The cable length between the signal feeder source and the first amplifier can be obtained according to Figure 5-39 and Figure 5-40. For example, suppose that the attenuation is 4.3dB/100 for the leaky cable, you can mark a plumb line at the point indicating 4.3dB. This plumb line will intersect the curve indicating 19 dB at a point, and then you mark a horizontal line starting from this point. The horizontal line will intersect the right vertical axis at a point. And this point shows the cable length. According to this example, the distance between the signal source and the first amplifier is 440m (that is, 19/4.3 = 440m).

Cable length between amplifiers in concrete cables:

According to the previous figures, the left vertical axis indicates “Required RADIAMP Gain”, which can be replaced by the radial loss of the leaky cable, but it makes no difference.

III. Needed amplifier gain

Before calculating the maximum amplifier gain, you must collect the following information:

The minimum acceptable signal level (dBm)
Coverage factor (dB)
The maximum output loss allowed by a single carrier (dBm)

If the amplifier is not added, the signal level output by the leaky cable for the longest transmission distance is equal to the difference of the minimum acceptable signal level and the coverage factor.
The signal level at the leaky cable beyond the longest transmission distance may be lower the minimum acceptable level, so an amplifier must be added to amplify the signals to the maximum output power allowed by a single carrier. The amplification of this power is related to the specifications of the amplifier and the number of carriers. If the maximum output power allowed by a single carrier is known, the amplifier gain can be calculated as follows:

Needed amplifier gain = the maximum output power allowed by a single carrier (it depends on the number of carriers) – (the minimum acceptable signal level – coverage factor)

Along the leaky cable, the maximum output power allowed by each carrier of a bi-directional amplifier is related to the number of carriers that have been amplified. This is considered mainly for the intermodulation interference is present, because the intermodulation interference will increase with the total number of carriers that have been amplified.

Relationship between the maximum output power allowed by a single carrier and the number of carriers that have been amplified:

Needed amplifier gain = the minimum acceptable signal level – coverage factor + the maximum output power allowed by a single carrier.

According to the previous equation, if the minimum acceptable signal level is -85 dBm, the coverage factor is -77, and the maximum output power allowed by a single carrier is 5 dBm, the needed amplifier gain is 13 dB.

IV. Decide cable length between amplifiers
Before deciding the cable length between amplifiers, you must know the needed amplifier gain and the cable loss (dB/100m). Figure 5-39 and Figure 5-40 help you decide the cable length between amplifiers. For example, in a concrete tunnel, if the amplifier gain is 13 dB and the cable attenuation is 4.3dB/100m, the cable length between two amplifiers is 300m.
V. Decide the number of needed amplifiers
Before deciding the number of needed amplifiers, you must know the following information:
The cable length between the feeder source and the first amplifier
The cable length between amplifiers
The tunnel length
If the previous information is known, the following formula can be used to calculate the number of needed amplifiers. That is:
The number of amplifiers ≥ (the tunnel length – the cable length between the feeder source and the first amplifier)/(the cable length between amplifiers), rounding up to the nearest integer.
According to the formula, if the tunnel length is 1000m, the cable length between amplifiers is 300m, and the cable length between the feeder source and the first amplifier is 420m, 2 amplifies are needed. That is, (1000 – 420)/300 = 1.93, so the nearest integer is 2.
After deciding the number of needed amplifiers, you can optimize the distance between amplifiers. That is, you can obtain the distance between the two amplifiers by dividing the remaining distance by the number of needed amplifier. According to the previous example, it is 580/2 = 290m, namely, the distance between the two amplifiers is 290m.
VI. Remarks on leaky cable installation
The leaky cable must not touch any metal. Generally, a leaky cable must be installed at a spot 5m away from concrete walls and at least 10m away from metal walls. In addition, a leaky cable must be installed near to the coverage area. You cannot necessarily consider the line-of-sight propagation, because the signals leaking from the cable will fill the space nearby.
This section introduces the coverage solutions to tunnels in different length. In actual networking, the following coverage solutions may be used:
Micro base station (or repeater) + a single antenna
Micro base station (or repeater) + distributed antenna system
Micro base station (or repeater) + leaky cable
Before deciding which coverage solution should be adopted, you must consider the followings:
Is the GSM signal near the tunnel entrance strong enough?
Is there any available transmission link near the tunnel?
Generally, if the existed signal level near the tunnel entrance (including nearby mountains) is lower than -80 dBm, the micro base station is recommended. If it is greater than -80 dBm, the micro base station or the repeater is recommended. If problems concerning transmission are present, the repeater is recommended. When using the repeater, you must consider that certain isolation is required between repeaters.
I. Coverage solution to short tunnels
Generally, the tunnels shorter than 100m are defined as short tunnels. When planning the coverage for these tunnels, you must consider the coverage areas near the tunnels. If several tunnels are close to each other, you can install a base station or a repeater between the tunnels. If adopting a micro base station, you must adopt the bi-directional antenna. If the antenna gain is 5 dBi, you should install the antenna at the tunnel entrance so as to ensure coverage.
When designing tunnel coverage solutions, you must fully consider that fact that cars and trains move at a high speed, so how to ensure normal handover after the cars or trains steering into the tunnels is of vital importance.
If the repeater is used as the GSM signal source and the signals outside the tunnel and the signals within the tunnel belong to the same cell, no handover problem will occur. If the micro cell is used as the GSM signal source and the signals outside the tunnels and the signals within the tunnel belong to different cells, the signals in the outside cell will drop dramatically when the train steers into the tunnel. In this case, handover failure may occur and call drop will be resulted in.
To solve this problem, you can consider adopting the following methods:
Adopt the bi-directional antenna for the tunnel coverage, because it can provide enough overlapping area for handover.
Enable special handover algorithms, such as fast level fall handover algorithm. In this case, a mobile station can hand over to another cell when the signal level falls fast.
Select the directional antenna with small front-to-back ratio.
II. Coverage solution to middle-length tunnels
This section introduces several typical coverage solutions to railway tunnels.
The followings are a series of assumptions:
The Huawei BTS3001C (the maximum output power is 8W) is used as the GSM signal source.
The repeater with 1 amplified carrier and a maximum output power of 2W is considered.
The lowest receiving level is designed to -85 dBm, and the coverage probability is 90% (with a protection margin of 8 dB).
For railway tunnel coverage, because the train will affect signal transmission, if the antenna is installed at the tunnel entrance, the protection margin must be increased by 10 dB. If the antenna is installed in the tunnel, the protection margin must be increased by 5dB.
The dedicated directional antenna with the specification of DB771S50NSY, the horizontal half power angle of 60°, and the antenna gain of 8 dBi is used at the tunnel entrance.
The bi-directional antenna with the specification of K738446 and antenna gain of 5 dBi is used within the tunnel.
According to these assumptions, if a micro base station (39 dBm) is used as the GSM signal source, the coverage distance is 400m when the antenna with a gain of 8 dBi is installed at the tunnel entrance, and the coverage distance is 480m when the bi-directional antenna with a gain of 5 dBi is installed in the tunnel.
If a repeater (33 dBm) is used as the GSM signal source, the coverage distance is 250m when the antenna with a gain of 8 dBi is installed at the tunnel entrance, and the coverage distance is 360m when the bi-directional antenna with a gain of 5 dBi is installed in the tunnel.
Therefore, for the tunnels shorter than 500m, you can use the combination of a micro base station and a single antenna (or a repeater) for the tunnel coverage. For curve tunnels, you can install a bi-directional antaean in the tunnel.
According to on-site survey on the cross-section, the available antenna size, and the tunnel length, you can use the antenna with a higher gain to coverage the tunnels a little longer than 500m.

III. Coverage solution to long tunnels
For the tunnels longer than 500m, you need to use the distributed antenna system or the leaky cable for the coverage. The followings introduce the coverage realized by the combination of a micro base station and a leaky cable (or a repeater).
Hereunder is a series of assumptions:
The Huawei BTS3001C (the maximum output power is 8W) is used as the GSM signal source.
The repeater with 1 amplified carrier and a maximum output power of 2W is considered.
The lowest receiving level is designed to -85 dBm, and the coverage probability is 90% (with a protection margin of 8 dB).
The leaky cable with the specification of SLWY-50-22 and the radial loss of 5dB/100 m is used.
The coupler loss may be 77 dB when the 90% of signals are received.
According to these assumptions, if a micro base station (39 dBm) is used as the GSM signal source, the coverage distance is 800m when only the leaky cable but no amplifier is used. If a repeater (33 dBm) is used as the GSM signal source, the coverage distance is 680m when only the leaky cable but no amplifier is used. The coverage distance will be larger if leaky cables with smaller loss are used.
For the coverage of still longer tunnels, you must use amplifiers to amplify signals. That is, you can use either the distributed antenna system or the leaky cable for the coverage solution. In terms of technical indexes and installation space, coverage solution based on leaky cable is recommended. In terms of cost, you must select a suitable coverage solution base on actual conditions.
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