NB-IoT规划原理

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NB-IoT链路运算：Coverage extension

One of the objectives defined in the study item description is to achieve 20 dB coverage extension compared with legacy GPRS. The target for the NB-CIoT solution is to achieve this coverage extension objective while limiting the maximum MS transmit power to 23 dBm.

The NB-CIoT solution supports multiple coverage classes.

I. Normal coverage class, similar to legacy GPRS coverage.
II. Extended coverage class, corresponding to about 10 dB improvement relative to legacy GPRS.
III. Extreme coverage class, corresponding to 20 dB improvement relative to legacy GPRS.

From Tables B.1 and B.2, it can be observed that the overall MCL for legacy GPRS is 144.0 dB, since the uplink is limiting the MCL.

Table B.2: Link budget table for legacy GPRS uplink

	Uplink MCL based on TS 45.005[5] (adjusted for2 x Rx gain)
Transmitter	
(1) Total Tx power (dBm)	33
Receiver	
(2) Thermal noise density (dBm/Hz)	-174
(3) Receiver noise figure (dB)	3
(4) Interference margin (dB)	0
(5) Occupied channel bandwidth (kHz)	180
(6) Effective noise power = (2) + (3) + (4) + 10 log((5)) (dBm)	-118.4
(7) Required SINR (dB)	12.4 (See Note 1)
(8) Receiver sensitivity = (6) + (7) (dBm)	-106.0
(9) Receiver processing gain (dB)	5 (See Note 2)
Maximum coupling loss (MCL) = (1) – (8) + (9) (dB)	144.0
NOTE 1: This value has been derived from the "Receiver sensitivity" value shown in row (8) so is just shown for completeness. NOTE 2: This value is taken from TR 36.888[3] for the processing gain for a typical BS, and is assumed to include the use of two receive antennas at the base station.	

NB-IoT链路运算：MCL calculations for Uplink data and control channels

It has been shown that the target MCL of 164 dB can be met by the uplink data channels for both the stationary and non-stationary scenarios, which implies a coverage extension of 20 dB compared with legacy GPRS. Also, all data channels comfortably achieve the required throughput of 160 bps at the top of the (equivalent of) SNDCP layer. In addition, a very low false detection rate is ensured for random access requests.

Therefore, the objectives of the study in terms of coverage performance are achieved for uplink channels.

Furthermore, the required coverage performance is achieved with a MS transmit power of only +23 dBm. This MS transmit power is 10 dB lower than the maximum MS transmit power allowed by the study item of +33 dBm, but is considered to be more appropriate for the large majority of MSs due to the lower instantaneous current draw from the battery.

Table 7.3.6.1.5-3: MCL calculations for uplink data channels

	PUSCH Class-1		PUSCH Class-2	
	UL-SCH		UL-SCH	
	TU 1Hz	TU 25Hz	TU 1Hz	TU 25Hz
Transmitter				
(1) Total Tx power (dBm)	23	23	23	23
Receiver				
(2) Thermal noise density (dBm/Hz)	-174	-174	-174	-174
(3) Receiver noise figure (dB)	3	3	3	3
(4) Interference margin (dB)	0	0	0	0
(5) Occupied channel bandwidth (Hz)	3750	3750	3750	3750
(6) Effective noise power = (2) + (3) + (4) + 10 log((5)) (dBm)	-135.3	-135.3	-135.3	-135.3
(7) Required SINR (dB)	-7.0	-6.3	-7.0	-7.2
(8) Receiver sensitivity = (6) + (7) (dBm)	-142.3	-141.6	-142.3	-142.5
(9) Rx processing gain (dB)	0	0	0	0
Maximum coupling loss				
(10) MCL = (1) – (8) + (9) (dB)	165.3	164.6	165.3	165.5
Data rate at the SAP to the SNDCP (bps)	246.4	246.4	269.8	269.8

NOTE 1: The uplink TX power of +23 dBm is considered to be more appropriate for most low cost MSs than the maximum allowed TX power of +33 dBm. The PA efficiency of Class-2 using +23 dBm uplink TX power is expected to be lower than for Class-1, due to the non-constant envelope property of the Class-2 modulation.

NOTE 2: The Rx processing gain is reflected in "Required SINR" (for example, the receiver diversity gain in the uplink).

NOTE 3: The data rates at the SAP to the SNDCP are derived for UL-SCH Class-1 according to $85 \times 8/2.76 = 246.4$ bps, and for UL-SCH Class-2 according to $85 \times 8/2.52 = 269.8$ bps, based on the exception report payload size of 85 bytes and the corresponding block durations from Table 7.3.6.1.5-2.

NB-IoT链路运算：MCL calculations for Downlink data and control channels

Assuming a 43-10*log10(45) = 26.5 dBm transmit power per subcarrier, the maximal coupling losses (MCL) for PDSCH, PBCH, PDCCH and PUSCH are given in Table 7.3.6.1.4-4
From Table 7.3.6.1.5-1, all channels support larger than 164 dB MCL. At 164 dB MCL, the PDSCH can support a data rate 378 b/s at the equivalent of the SNDCP layer, higher than 160 b/s as specified in clause 4.1.1.

The MCL of MCS as listed in Table 7.3.6.1.4-3 for 25 Hz Doppler spread are listed in Table 7.3.6.1.4-5.
At 25 Hz Doppler spread, the PDSCH can support a data rate 756 b/s at the equivalent of the SNDCP layer, significantly higher than 160 b/s as specified in clause 4.1.1. Also 164 dB MCL are supported for PBCH and PDCCH with reduced number of repetitions.

Table 7.3.6.1.4-4: MCL of NB-CIoT, 1 Hz Doppler spread

Parameter	*PDSCH*	*PBCH PSI*	*PBCH SSI*	*PDCCH*
(1) Tx Power in Occupied Bandwidth (dBm)	32.5	38.2	38.2	32.5
(2) Thermal Noise Density (dBm)	-174	-174	-174	-174
(3) Occupied Bandwidth (kHz)	15	56.25	56.25	15
(4) Receiver Noise Figure (dB)	5	5	5	5
(5) Interference Margin (dB)	0	0	0	0
(6) Effective Noise Power (dBm) = (2)+10log10((3))+(4)+(5)	-127.2	-121.5	-121.5	-127.2
(7) Required SINR (dB)	-6.0	-7.4	-6.8	-4.9
(8) Receiver Sensitivity (dB) = (6)+(7)	-133.2	-129.0	-128.3	-132.1
(9) Maximal Coupling Loss (dB) = (1)-(8)	165.7	167.1	166.5	164.6
NOTE: No power reduction due to PAPR is assumed.				

Table 7.3.6.1.4-5: MCL of NB-CIoT, 25 Hz Doppler spread

Parameter	*PDSCH MCS1*	*PBCH PSI 2 Rep.*	*PBCH SSI 2 Rep.*	*PDCCH 1 Rep.*
(1) Tx Power in Occupied Bandwidth (dBm)	32.5	38.2	38.2	32.5
(2) Thermal Noise Density (dBm)	-174	-174	-174	-174
(3) Occupied Bandwidth (kHz)	15	56.25	56.25	15
(4) Receiver Noise Figure (dB)	5	5	5	5
(5) Interference Margin (dB)	0	0	0	0
(6) Effective Noise Power (dBm) = (2)+10log10((3))+(4)+(5)	-127.2	-121.5	-121.5	-127.2
(7) Required SINR (dB)	-4.8	-5.0	-4.8	-6.3
(8) Receiver Sensitivity (dB) = (6)+(7)	-132.0	-126.5	-126.3	-133.5
(9) Maximal Coupling Loss (dB) = (1)-(8)	164.5	164.7	164.5	166.0
NOTE: No power reduction due to PAPR is assumed.				

NB-IoT话务模型：Cellular IoT device density per cell site sector

The cellular IoT device density per cell site sector is calculated by assuming 40 devices per household. The household density is based on the assumptions of TR 36.888 [3] for London in Table E.1-1.

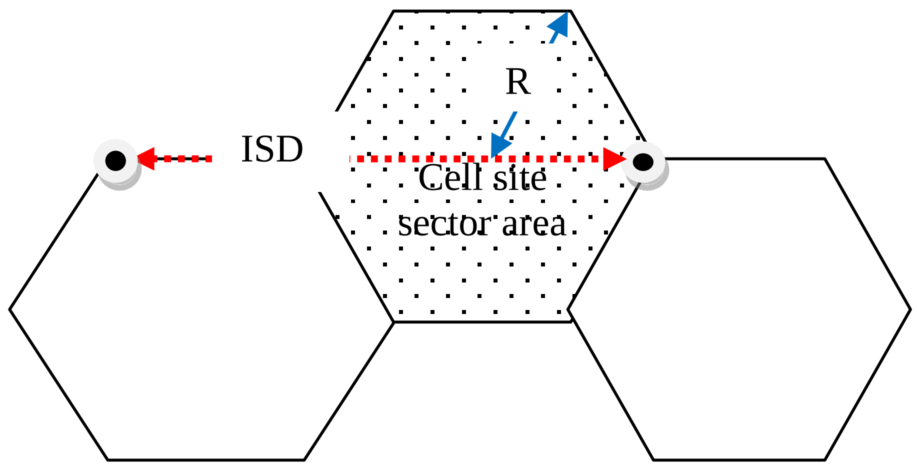


Figure E.1-1: Cell site Sector area definition

Calculation:
Inter-site Distance (ISD) = 1732m
Cell site sector radius, R = ISD/3 = 577.3m
Area of cell site sector (assuming a regular hexagon) = 0.86 Sq Km
Number of devices per cell site sector = Area of cell site sector*Household density per Sq km*number of devices per household = 52547

Table E.1-1: Device density assumption per cell

Case	Household Density per Sq km	Inter-site Distance (ISD) (m)	Number of devices within a household	Number of devices within a cell site sector
Urban	1517	1732 m	40	52547

NB-IoT话务模型： Traffic models for Cellular IoT

Traffic component	Uplink data volume pr transmission (application layer)	Downlink data volume pr transmission (application layer)	Uplink transmission interval	Downlink transmission interval
Mobile Autonomous Reporting (MAR) exception reports	20 bytes	Ack with 0 bytes payload	generally rare, typically occurring every few months or even years	generally rare, typically occurring every few months or even years
Mobile Autonomous Reporting (MAR) periodic reports	Pareto distributed (alpha = 2.5) , minumum (beta) = 20 bytes, cutoff = 200 bytes => Mean = 33 bytes	Ack with 0 bytes payload	40%: Once per day 40%: Once every 2 hours 15%: Once per hour 5%: Once every 30 min => Mean = 0.47 times per hour	Generated for 50% of the uplink transmissions
Network Command	Pareto distributed (alpha = 2.5) , minumum (beta) = 20 bytes, cutoff = 200 bytes => Mean = 33 bytes	20 bytes	Generated for 50% of the downlink transmissions	40%: Once per day 40%: Once every 2 hours 15%: Once per hour 5%: Once every 30 min => Mean = 0.47 times per hour
Software updates/ reconfiguration model	Ack with 0 bytes payload	Pareto distributed (alpha = 1.5) , minumum (beta) = 200 bytes, cutoff = 2000 bytes	one UL application layer ACK for each DL software/ reconfiguration application payload	Once every 180 days

◆The split of devices between MAR periodic and Network Command is MAR periodic (80%) and Network Command (20%).
◆帕累托因对意大利20%的人口拥有80%的财产的观察而著名，后来被约瑟夫·朱兰和其他人概括为帕累托法则（80/20法则），后来进一步概括为帕累托分布的概念

NOKIA

NB-IoT话务模型： Assumptions for header overhead

The total packet size at the equivalent of the SNDCP layer (excluding equivalent of SNDCP layer overhead) is made up of the application payload size and header overhead of protocols below the application layer and above the equivalent of the SNDCP layer.

Table E.2-3: Assumptions for header overhead above the equivalent of the SNDCP layer

Protocol	Size in bytes	
COAP	4	
DTLS	13	
UDP	8	
IP	40 (without IP header compression)	4 (with IP header compression)
Total header size	65	29

Header overhead=65

- MAR periodic session：
  - Uplink: 33 + 65 = 98 bytes
  - Downlink: 1/2×（0 + 65）= 33 bytes
- Network command session：
  - Uplink: 1/2×（33 + 65） = 49 bytes
  - Downlink: 20 + 65= 85 bytes

Header overhead=29

- MAR periodic session：
  - Uplink: 33 + 29 = 62 bytes
  - Downlink: 1/2×（0 + 29）= 15 bytes
- Network command session：
  - Uplink: 1/2×（33 + 29） = 31 bytes
  - Downlink: 20 + 29= 49 bytes

NB-IoT系统仿真： BPL modelling

The CDFs of the BPL for all the MSs in the simulation, after each MS has selected its preferred cell based on minimizing the overall path plus penetration loss, are shown in Figure 7.3.6.2-1

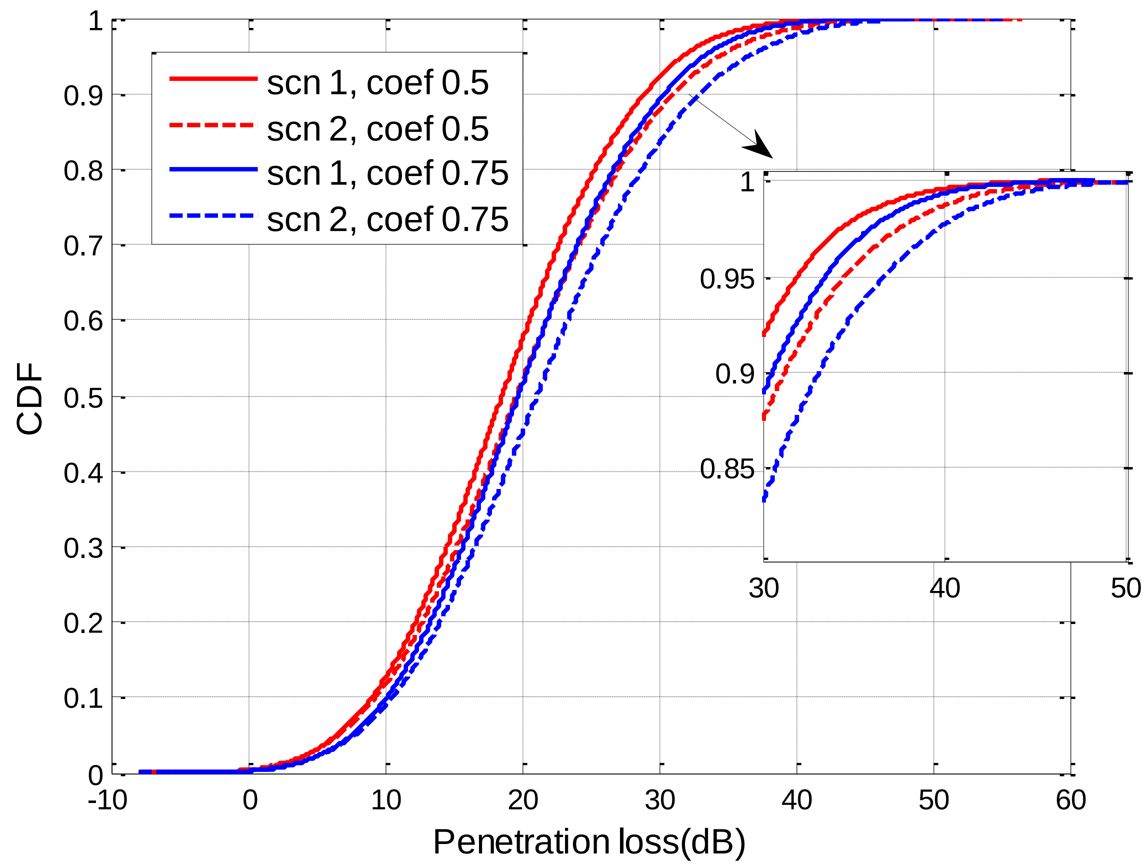


Figure 7.3.6.2-1. BPL modelling results

◆BPL 为Building penetration loss缩写

NB-IoT系统仿真： Simulation cases

The definitions of eight simulation cases are shown in Table 7.3.6.2-1, corresponding to scenarios with and without IP header compression and with different parameters relating to building penetration loss (BPL).
To determine the maximum capacity of the system, each simulation case is run for a number of offered loads (denoted by "#MS per sector").

Table 7.3.6.2-1: Definition of simulation cases

Case no.	MS Modulation class	IP header compression	BPL scenario	BPL inter-site correlation coefficient	Offered load (#MS per sector)
1	Class-1	Yes	Scenario 1	0.5	12857, 25714, 52547, 64285, 77142
2	Class-1	No	Scenario 1	0.5	12857, 25714, 52547, 64285, 77142
3	Class-1	Yes	Scenario 1	0.75	12857, 25714, 52547, 64285, 77142
4	Class-1	No	Scenario 1	0.75	12857, 25714, 52547, 64285, 77142
5	Class-1	Yes	Scenario 2	0.5	12857, 25714, 52547, 64285, 77142
6	Class-1	No	Scenario 2	0.5	12857, 25714, 52547, 64285, 77142
7	Class-1	Yes	Scenario 2	0.75	12857, 25714, 52547, 64285, 77142
8	Class-1	No	Scenario 2	0.75	12857, 25714, 52547, 64285, 77142
NOTE: With IP header compression, the protocol overhead above (equivalent of) SNDCP layer is 29 bytes. Without IP header compression, the protocol overhead above (equivalent of) SNDCP layer is 65 bytes. See Table E.2-3 in Annex E for more details. The header overhead of (equivalent of) SNDCP down to MAC (e.g. SNDCP, LLC, RLC/MAC in Gb mode) layer can be estimated to be 15 bytes (4 bytes for SNDCP + 6 bytes for LLC + 2 bytes for MAC + 3 bytes for CRC).					

NB-IoT系统仿真： Capacity results

Capacity results are shown in Figure 7.3.6.2-2. The vertical red line represents the target number of devices within a sector taken from Table E.1-1 in Annex E. The black line represents the "ideal capacity" (i.e. assuming every uplink report is successfully delivered by the system), so is a straight line through the origin with gradient determined by the parameters of the traffic model. The corresponding uplink MAR failure probability is shown also in Figure 7.3.6.2-3.

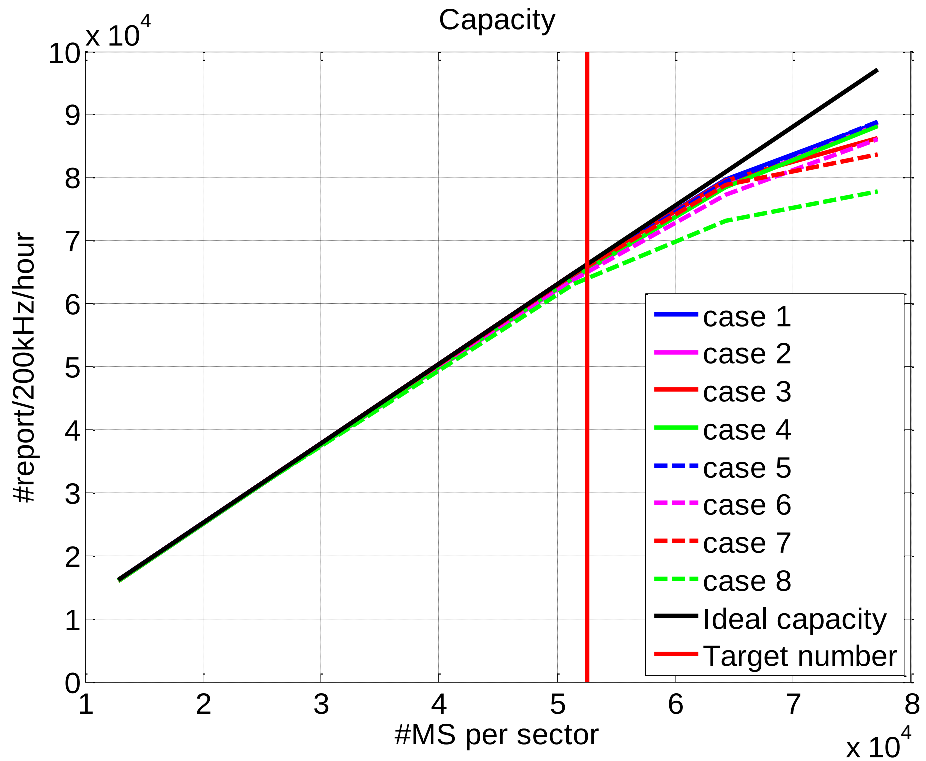


Figure 7.3.6.2-2: Capacity (in #reports/200 kHz/hour)

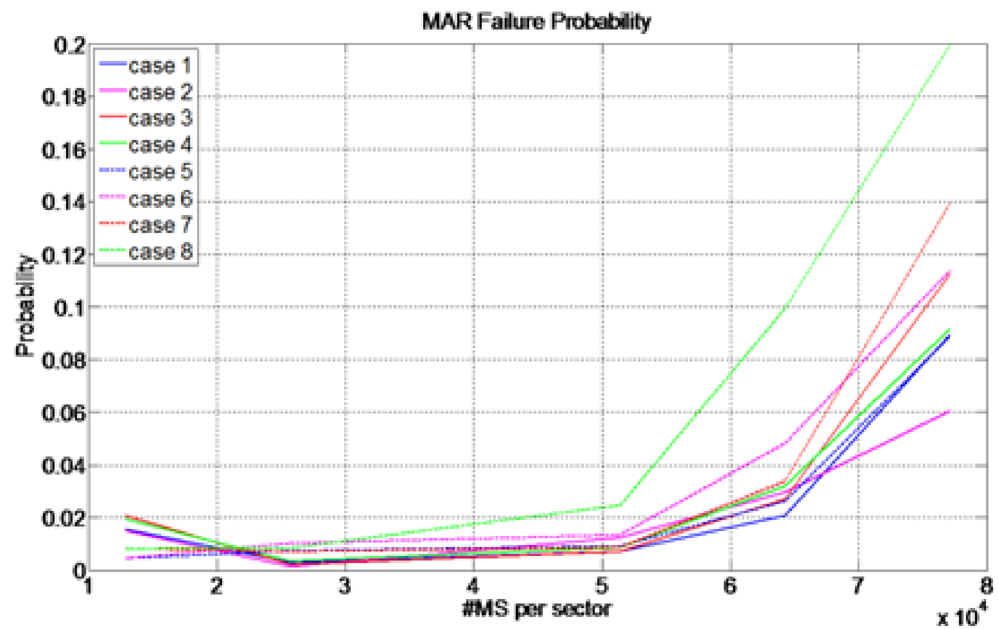


Figure 7.3.6.2-3: UL MAR Failure Probability

一组仿真数据（来源：NB-IoT planning engineering guideline RAN）

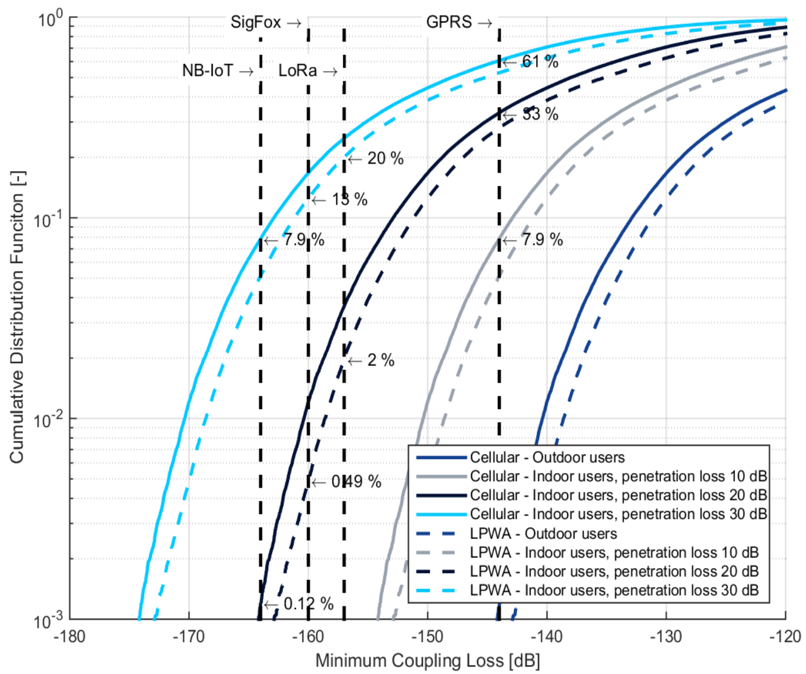


Figure 7: Simulated NB-IoT coverage using real operator site positions (only outdoor sites are included in the calculations) [9]

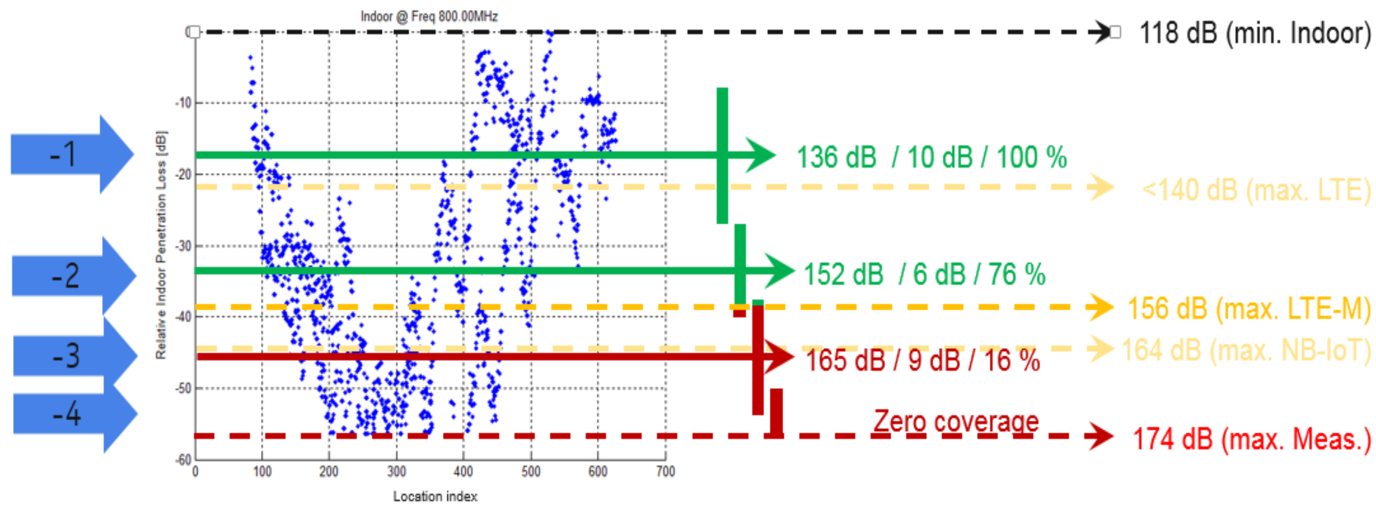


Figure 8: Measurements of outdoor-to-indoor coverage in deep parking basement [14]

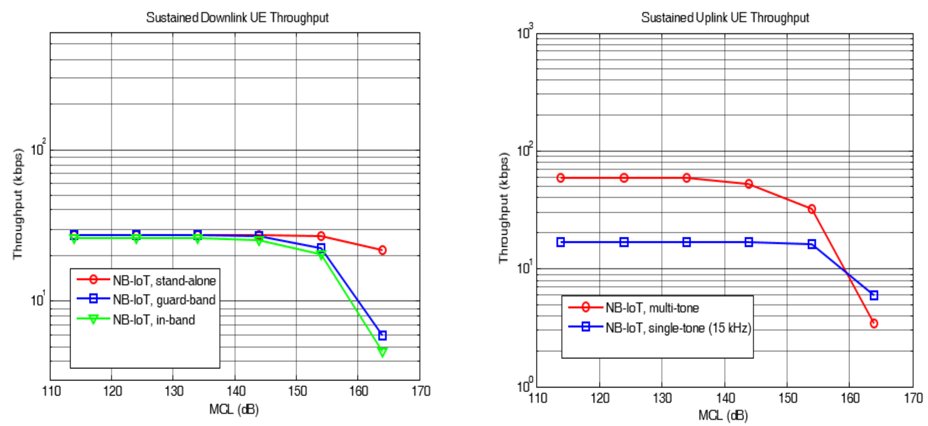


Figure 9: Sustained throughput versus coverage [15]

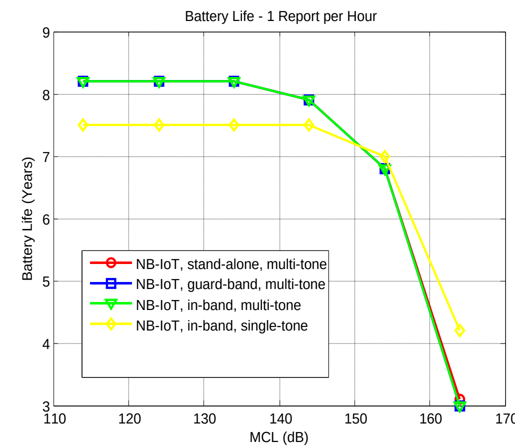
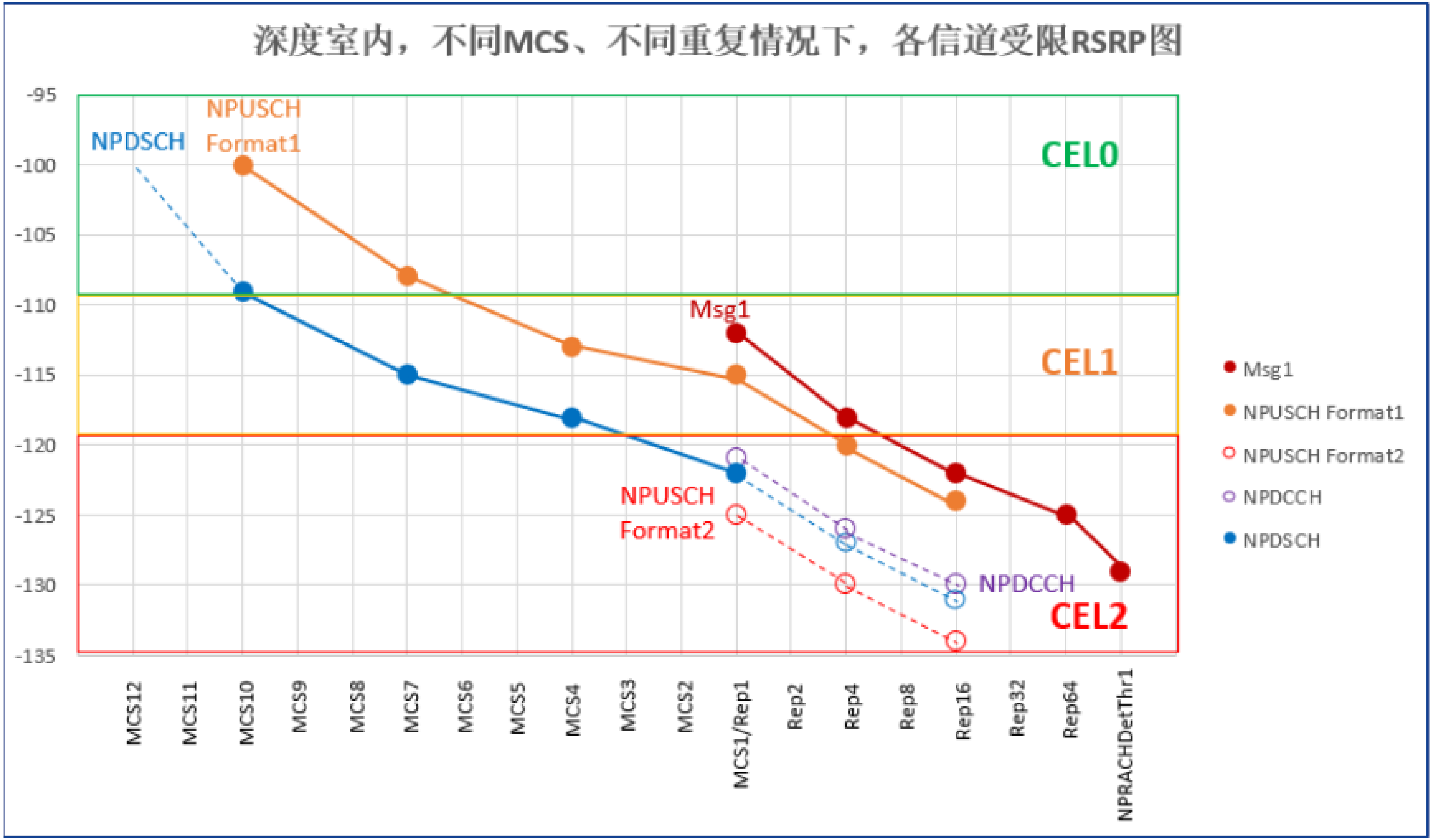


Figure 10: Battery life versus coverage [15]

这组数据告诉我们：

- NB-IoT也不能保证全覆盖；
- 边缘场景，即使NB-IoT可用，电力消耗和吞吐量问题也是不容忽视；

上海电信深度室内极限覆盖测试结果（NRS=29，NPI=-123）



宁波市中心区域仿真结果（未考虑室内穿透损耗）

INPUT：

规划区面积： 84.95km^2

站点数：118

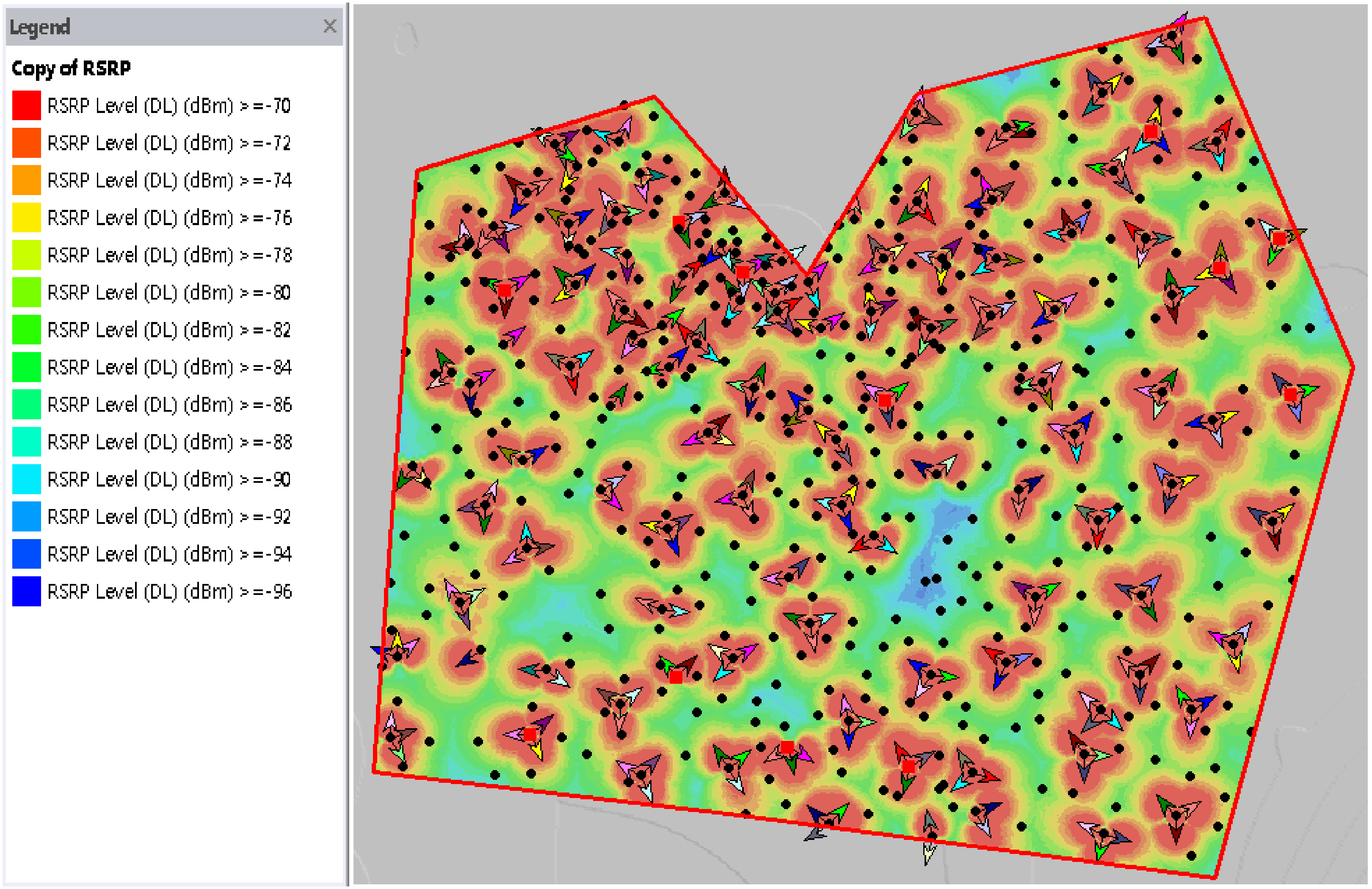
站间距：849m

频段设置：900M

RS EPRE：32.2dBm

OUTPUT：

RSRP>=-84dBm 94.5%



福州市中心区域仿真结果（仅供参考）

INPUT：

规划区面积： 24.92km^2

站点数：34

站间距：613m

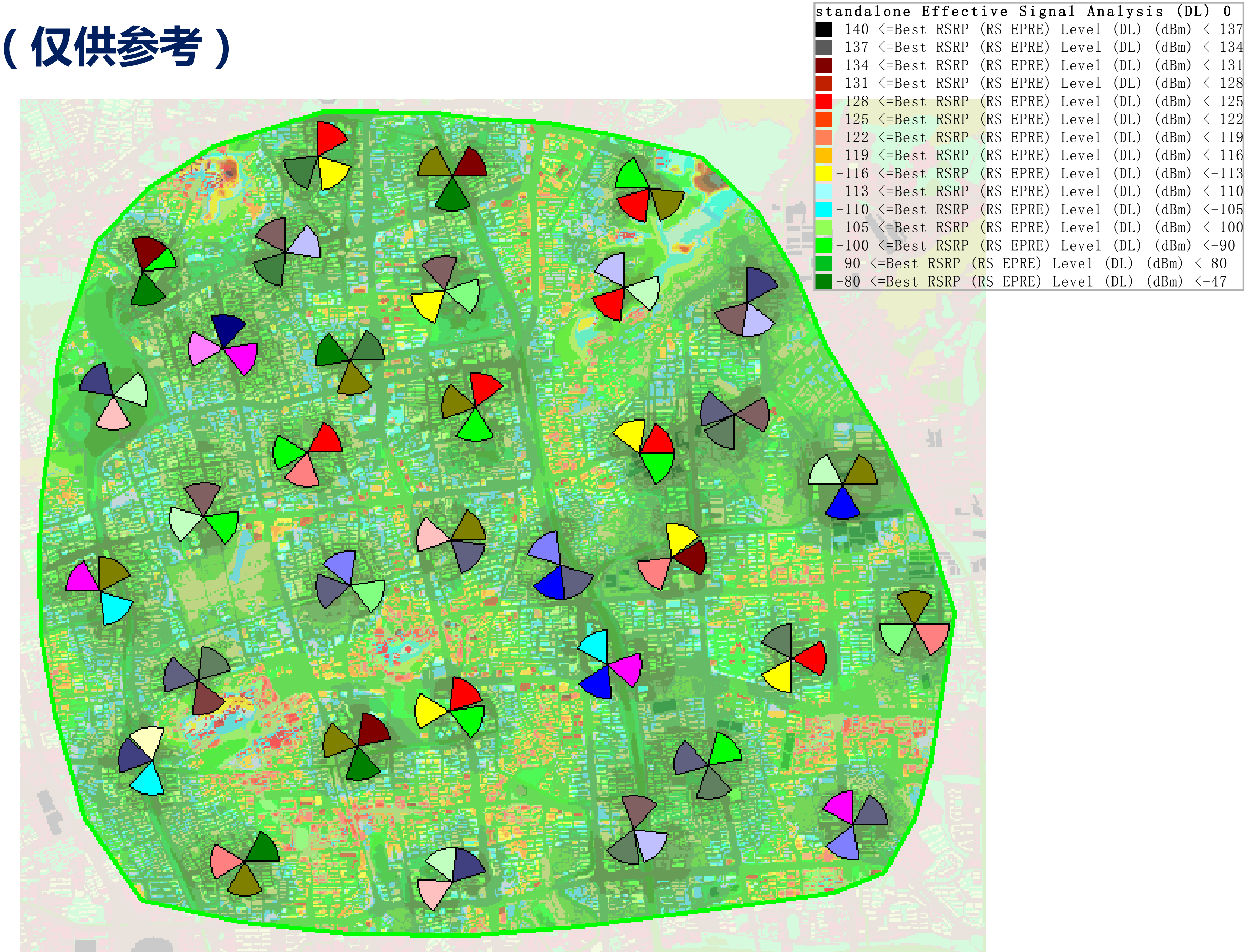
频段设置：900M

RS EPRE：32.2dBm

OUTPUT：

RSRP>=-116dBm 95.38%

RSRP>=-123dBm 99.05%



影响覆盖仿真结果准确性的几个因素

1、900M传播模型不准确（默认设置下仿真结果过于乐观），也无现网MR数据以供模型矫正，由于室内分布的存在，现网MR数据也无法完全反映宏站覆盖室内场景的覆盖情况

2、NB与现网站点是按比例规划建站的，无法完全沿用原站点工参，方位角、下倾角非最优配置

3、仿真软件不支持NB，无法模拟室内覆盖场景的穿透损耗（即BPL）