NB-IoT, eMTC, eMIMO and Massive CA: First Africa Engineering Experimental Results Towards the Delivery of 5G/IoT Smart Technologies Applications

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Abstract —5G RF technology is an essential part of the wireless mobile technology. Technically, 5G is predicted to empower people-thing and thing-thing interconnections by combining wireless technologies and networks. Our university has been actively support research on 4G/5G/IoT, in which the NB-IoT, eMTC and Massive Carrier Aggregation new features challenge are of big interest. New 5G trials put forward a lot of prerequisites for new RF interface in terms of radio bandwidth, power issues, as well as the huge number of connections for IoT capacity management and optimization. Based on Morocco's current situation, this paper first discusses the 5G technologies; In addition, we will discuss IoT SoftRadio application support, and NB-IoT master plan recap. At last, based on the current plan of 5G RF KPIs management according to first Morocco 5G trail Results and Deployment plans.

Index Terms—NB-IoT, 5G, eMTC, eMIMO, CA

I. Introduction

5G introduced a new radio technology for wireless. It is mainly used for scenarios that this feature provide: low rate, deep coverage, low power consumption, and considerable connections [1], [2].

II. NB-IoT Radio and Performance

Fig. 1 illustrates the mapping Application scenarios of IoT.

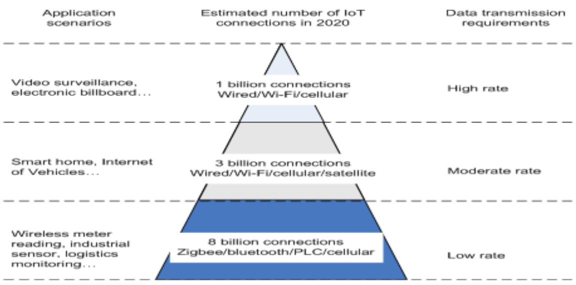

Fig. 1. Application scenarios of IoT

Ref [3] introduce the basic concepts of NB-IoT include physical channel, physical channel frequency-domain structure, physical channel time-domain structure, coverage level, and aggregation level.

A. Physical Channel

In [4] there are three types of downlink physical channels for NB-IoT, which are described as follows:

- Narrowband Physical Broadcast Channel (NPBCH): responsible for transmitting master information blocks (MIBs).
- NPDCCH: responsible for carrying the downlink control information (DCI).
- NPDSCH: responsible for carrying downlink data.

There are two types of uplink physical channels for NB-IoT, which are described as follows:

- NPUSCH: responsible for carrying uplink data.
- NPRACH: responsible for carrying random access messages.

Fig. 2 illustrates the mapping relationships between physical channels and transport channels.

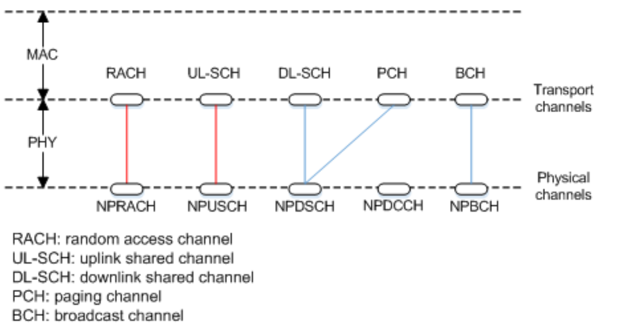

Fig. 2. Mapping relationships between physical channels and transport channels

B. NB-IoT RF Deployment Mode Proposal

This section describes the Standalone Deployment of NB-IoT; there are two options for standalone deployment:

- Refarming
- Refarming enables part of the spectrum resources for a RAT to be used by NB-IoT, without affecting the functionalities of that RAT. Typically, GSM spectrum resources are spared for NB-IoT by refarming with guard bands reserved between them. The GSM network is

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replanned to minimize the impact of refarming on GSM services. [4]

Fig. 3-1 uses 1:1 deployment as an example. In this example, two GSM carriers are allocated to the NB-IoT network and a guard band of 100 kHz is reserved between NB-IoT and GSM. In refarming deployment, the GSM frequencies in the entire buffer zone area need to be refarmed to reduce interference even if NB-IoT is not deployed. [3]

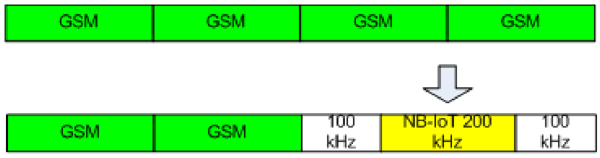

Fig. 3-1 Refarming deployment

- Using idle spectrum resources

Operators may own spectrum resources with non-standard bandwidths, which do not meet the communications requirements of certain RATs and therefore are not in use. Using these resources, NB-IoT can implement narrowband communications. Deploying NB-IoT on idle spectrum resources requires that sufficient guard bands be reserved between NB-IoT and those RATs, preventing impact on existing networks. The application scenarios are as follows: [4]

➢ GSM idle spectrums are used to deploy the NB-IoT network, as shown in Fig. 3-2.

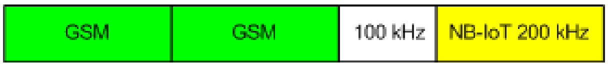

Fig. 3-2 NB-IoT deployment on GSM idle spectrum resources

➢ UMTS idle spectrums are used to deploy the NB-IoT network, as shown in Figure 3-3. [4]

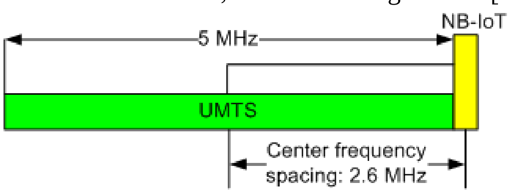

Fig. 3-3 NB-IoT deployment on UMTS idle spectrum resources

➢ LTE idle spectrums are used to deploy the NB-IoT network, as shown in Fig. 3-4.

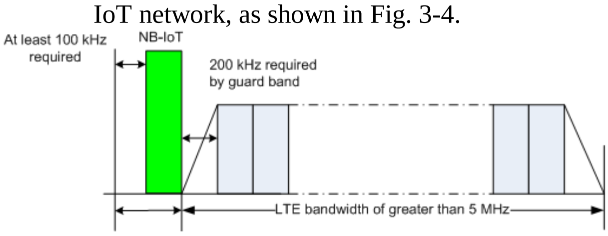

Fig. 3-4 NB-IoT deployment on LTE idle spectrum resources

This section describes the LTE Guardband Deployment of NB-IoT. [4]

To prevent adjacent-carrier interference or inter-RAT interference for existing RATs, a certain bandwidth must be reserved in addition to the valid bandwidth. This bandwidth is referred to as "guard band". The guard band between carriers is generally greater than or equal to 180 kHz. NB-IoT is a narrowband communication technology in which a bandwidth of 180 kHz is allocated to both the uplink and downlink. Therefore, services can be deployed on the guard bands of existing RATs, which eliminates the need for new spectrum and improves the utilization of old spectrum.

In guard band deployment, NB-IoT services are now deployed on LTE FDD guard bands, as shown in Figure 3-5. This deployment mode must meet the requirements specified in 3GPP TS 36.101 (Release 13). [4]

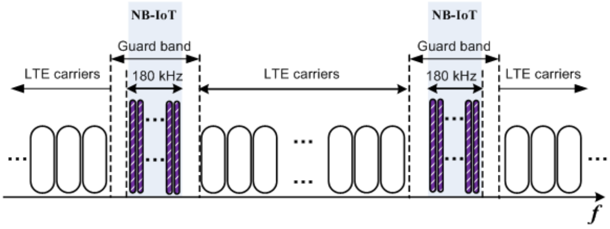

Fig. 3-5 LTE guard band deployment

For example, if the LTE FDD bandwidth is greater than or equal to 10 MHz, guard bands are sufficient for NB-IoT deployment, as shown in Figure 3-6. If the LTE FDD bandwidth is less than 10 MHz, the NB-IoT network cannot be deployed because of guard band insufficiency. [4]

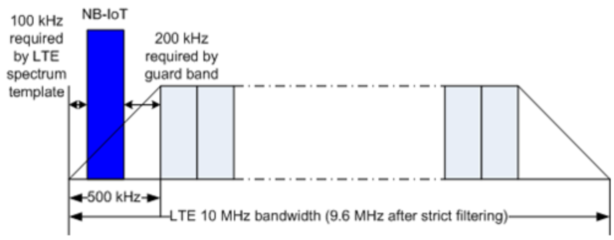

Fig. 3-6 LTE guard band deployment (10 MHz LTE FDD bandwidth as an example)

In-band deployment is a typical deployment scenario, in which operators deploy NB-IoT using existing LTE FDD in-band RBs, as shown in Fig. 3-7. [4]

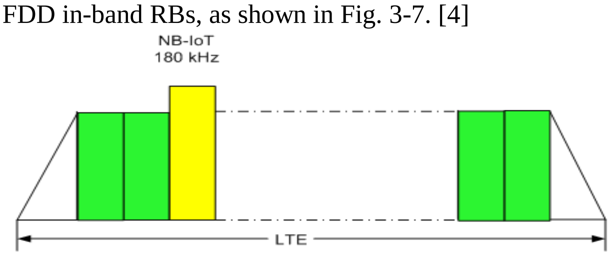

Fig. 3-7 LTE In-band deployment

III. EMTC Radio and Network Performance

eMTC is an IoT technology evolved on basis of the 3GPP protocols. It is mainly used for scenarios that feature medium and low rates, deep coverage, low power consumption, and massive connections. [5]

eMTC provides the following benefits:

- Maximum spectrum utilization
- eMTC can be deployed on existing LTE networks, fully utilizing current spectrum resources of operators for maximized spectral usage.
- Support for a large number of low- and medium-rate users
- The low-rate and low-activity service model supports a large number of users.
- Deep coverage
- The coverage gains provided by eMTC are 15 dB greater than those provided by a common LTE network with the help of time-domain repetition and other technologies.
- Low power consumption of UEs
- By using enhanced discontinuous reception (eDRX) and power saving mode (PSM), eMTC shortens the receive/transmit duration of UEs and therefore reduces their power consumption.

Fig. 4 illustrates the end-to-end network architecture of eMTC.

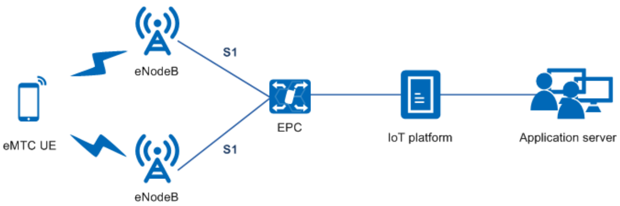

Fig. 4. eMTC network architecture

To ensure normal functioning of eMTC UEs on an 5G network, this feature performs enhanced processing on the following aspects:

- Physical channel management
- Cell management
- Idle mode management
- Connected mode management
- Overload control
- DRX for UEs in connected mode
- Random access control and RACH optimization
- Scheduling
- Power control
- LCS

M2M services have high power saving requirements. This feature is introduced to save power of eMTC UEs and support the M2M solution with low power consumption to prolong UE standby time and improve user experience. [5]

By extending paging cycles for UEs in idle mode, this feature reduces their monitoring times and power consumption. [6],

eMTC UEs and common UEs coexist in a cell. The cell management procedures for eMTC UEs are the same as those for common UEs.

The bandwidth of an eMTC-capable cell must be 5 MHz or higher. [6]

<u>Network Impact</u>

System Capacity

- Downlink traffic volume and throughput in the cell
  Downlink traffic volume and throughput will decrease in a cell serving both eMTC and common UEs. This is because they share PRB resources in the cell and MIB, SIB, and services for eMTC will consume PRB resources. Therefore, PRB resources available to common UEs decrease.
- Uplink traffic volume and throughput in the cell
  Uplink traffic volume and throughput will decrease in a cell serving both eMTC and common UEs. This is because they share PRB resources in the cell and PRACH, PUCCH, and eMTC services will consume PRB resources. Therefore, PRB resources available to common UEs decrease.
- CPU Usage
  CPU usage will increase, as a result of system processing for eMTC UEs.
- User-perceived throughput
  UL/DL throughput perceived by users of common UEs will decrease in a cell serving both eMTC and common UEs because they share PRB resources in the cell. Therefore, PRB resources available to common UEs decrease.[6]

Network Performance

- The RRC setup success rate and handover rate may decrease in a cell serving both eMTC and common UEs because the total number of RRC connection resources in the cell is fixed. The RRC connection setup failure possibility increases, as the RRC connection specifications available to common UEs decrease.
- When there are a large number of UEs in coverage enhancement mode, the number of messages that require retransmission will increase. The number of users that can access the cell will decrease as a result of SRI resource insufficiency.
- After eMTC is enabled, the online duration of common UEs will increase as a result of their reduced throughput. The average number of users will therefore slightly increase in the cell. The access of eMTC UEs to the cell will also contribute to the increase in the average number of users.
- PRB usage will increase in a cell serving both eMTC and common UEs. This is because they share PRB resources in the cell and eMTC UEs consume UL PRB overhead. Counters related to uplink MCS, BLER, and other factors are more likely to fluctuate because major changes will occur to the PRB resource usage and scheduling resource allocation will be more fragmented in an eMTC-enabled cell.
- PRB usage will increase in a cell serving both eMTC and common UEs. This is because they share PRB resources in the cell and eMTC UEs consume DL PRB overhead. After eMTC is enabled, PRB resource allocation for scheduling will be more fragmented and counters related to downlink MCS, BLER, CQI, and other factors are more likely to fluctuate. When RBG fragments cannot be fully used in a high load scenario, the DL

PRB usage will slightly decrease and the number of DL scheduling UEs in each TTI may increase. This will increase the DL CCE usage.

With the fast evolution of radio communication technologies, radio communication is not limited only to radio calls. With the development of the Internet of Things (IoT), communications between machines are becoming very important. Our paper defines this type of communications as machine type communication (MTC). [6]

IV. EMIMO AND CA: BOOST 5G

Enhanced multiple-input multiple-output (eMIMO) is a feature that improves the performance of cells with four transmit channels (4T cells). The feature consists of a series of functions. The following lists the applicable functions under different network loads: [7]

- When network load is low, coordinated pilot scheduling can offer noticeable benefits.
  Coordinated pilot scheduling reduces cell-specific reference signal (CRS) interference on intra-frequency neighboring cells and increases their average downlink UE throughput.
- When network load is moderate, fast beam alignment can offer noticeable benefits.
  Fast beam alignment rapidly obtains accurate precoding matrix indications (PMIs) at shorter reporting intervals and improves the beamforming effect.
- When network load is high, downlink multi-user multiple-input multiple-output (MU-MIMO) can offer noticeable benefits.

Downlink MU-MIMO can be performed in transmission mode 4 or 9 (TM4 or TM9). It increases the average downlink UE throughput. [7]

Based on the increasing traffic volume in densely populated urban areas, the capacity requirements in next few years are predicted to increase threefold to sixfold, and the spectrum resources in the 1.8 GHz to 2.6 GHz bands are so limited that they must be fully utilized.

The Vertical Multiple Sectors (VMS) function provided by the 3D Beamforming feature allows a single cell in a sector served by an antenna to be configured as two separate cells. The original cell is then split into an inner cell and an outer cell. [7]

In a cell served by an eNodeB with a 2T2R 3-sector configuration, VMS increases the downlink average cell traffic volume, average UE throughput, and cell-edge UE throughput by up to 80%, 70%, and 90%, respectively. [7]

The increases are closely related to whether the cells using VMS provide continuous coverage and how many UEs are distributed in inner and outer cells. The more contiguous the cell coverage and the more close to 50% the number of UEs in each inner cell, the higher the gains of VMS.

If a pair of inner and outer cells are imbalanced in their loads, dynamic load balancing between the cells helps achieve a further increase of up to 10% in the downlink average UE throughput and in the downlink average cell traffic volume.

For each eNodeB, three cells will turn into six cells on two layers, with each cell covering an area whose horizontal angle is 120 degrees, as illustrated in the following figure.

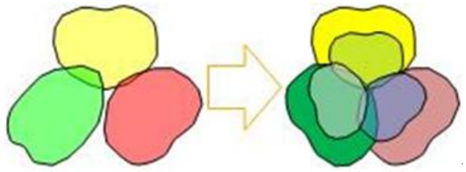

Fig. 5. 5G six cells solution

System Capacity

VMS increases system capacity considerably in contiguous urban coverage areas. In a cell served by an eNodeB with a 2T2R 3-sector configuration, VMS increases the downlink traffic volume by up to 80%. The increases are closely related to whether the cells using VMS provide continuous coverage and how many UEs are distributed in inner and outer cells. The more contiguous the cell coverage and the more close to 50% the number of UEs in each inner cell, the higher the gains of VMS. [7]

If a pair of inner and outer cells are imbalanced in their loads, dynamic load balancing between the cells helps achieve a further increase of up to 10% in the downlink average UE throughput and in the downlink average cell traffic volume.

Network Performance

- Perceivable downlink throughput
  When the downlink PRB usage in a cell exceeds 70%, VMS increases average UE throughput by up to 70% and increases cell-edge UE throughput by up to 90%. However, in the overlapping areas between inner and outer cells, co-channel interference may lead to a decrease in average perceivable throughput.
- Downlink peak data rate
  The percentage of times rank 1 is reported will increase, resulting in a lower probability that a single UE achieves the peak data rate.

Carrier Aggregation for Downlink 4CC and 5CC

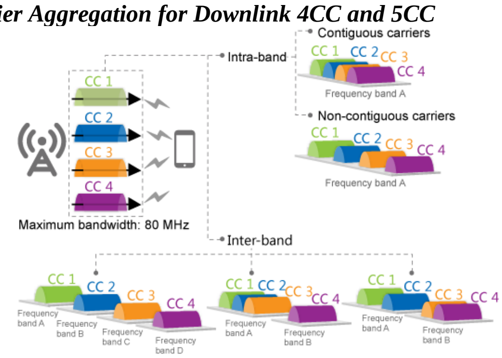

Fig. 6-1 Downlink 4CC aggregation

This feature allows a maximum of 100 MHz downlink bandwidth for a CA UE. By aggregating four or five intra- or inter-band carriers, operators can provide higher bandwidths and improve service quality for UEs. Figure 6-1 illustrates downlink 4CC aggregation. [8]

Fig. 6-2 illustrates downlink 5CC aggregation.

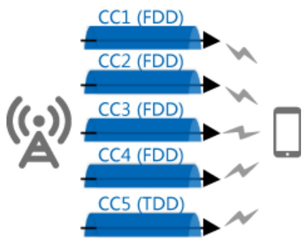

Fig. 6-2 Downlink 5CC aggregation

The peak downlink data rate varies depending on the number of FDD and TDD CCs in the downlink. The following data is based on the assumption that 2x2 MIMO is used and the TDD carrier serves a TDD cell.

- 2CC aggregation helps achieve 260 Mbit/s, which is equal to 150 Mbit/s on a single FDD carrier plus 110 Mbit/s on a single TDD carrier.
- 3CC aggregation helps achieve 410 Mbit/s, which is equal to 300 Mbit/s on two FDD carriers plus 110 Mbit/s on a single TDD carrier.
- 4CC aggregation helps achieve 560 Mbit/s, which is equal to 450 Mbit/s on three FDD carriers plus 110 Mbit/s on a single TDD carrier.
- 5CC aggregation helps achieve 710 Mbit/s, which is equal to 600 Mbit/s on four FDD carriers plus 110 Mbit/s on a single TDD carrier.

V. NB-IoT 5G Trial Results and Discussion

The SoftRadio is a type of software used as a substitution of Narrowband Internet of Things (NB-IoT) eNodeBs and evolved packet cores (EPCs) during testing. [1]

The SoftRadio helps NB-IoT UE developers make and verify NB-IoT UEs, without deploying the NB-IoT eNodeB and EPC and using NB-IoT UE chip display teams, greatly improving NB-IoT UE commissioning efficiency.

Fig. 7.1 illustrates the position of the SoftRadio on a network.

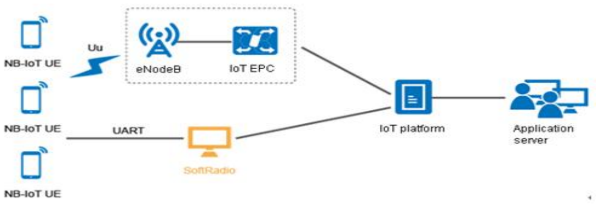

Fig. 7-1 Network architecture

Functions of network elements (NEs) on the above network are as follows:

- NB-IoT UE

NB-IoT UEs, such as smart water meters and gas meters, are connected to an eNodeB over the Uu interface.

- SoftRadio

The SoftRadio is a type of software used to substitute NB-IoT eNodeBs and EPCs during testing.

- eNodeB

An eNodeB processes messages concerning network access over the Uu interface, manages cells, and forwards non-access stratum (NAS) data to a higher-layer NE. An eNodeB is connected to the NB-IoT EPC over the S1-lite interface.

- NB-IoT EPC

An NB-IoT EPC exchanges information with NB-IoT UEs at the NAS layer and forwards data related to NB-IoT services to the IoT platform.

- IoT platform

The IoT platform converges different types of IoT data from various access networks and then forwards the data to a required service application based on the data type.

- Application server

An application server works as an IoT data convergence point and processes data in compliance with customer requirements.

Adding and Registering an NB-IoT Device

1. In the navigation tree of the SoftRadio interface, click Dashboard to navigate to the Dashboard interface.

2. On the Dashboard interface, click next to Devices to expand the Add Device interface, as illustrated in Fig. 7-2.

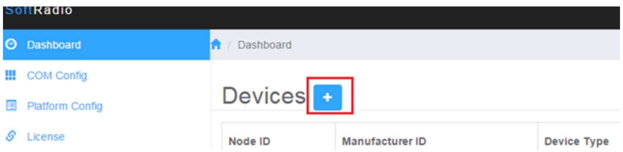

Fig. 7.2 Add device interface

3. In the Add Device interface, enter required device information under Device Info, as illustrated in Fig. 7-3.

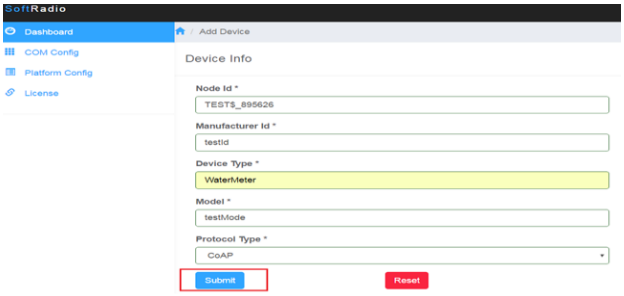

Fig.7-3 Device Info interface

Descriptions of required device information:

– Node Id uses the verification code obtained from the IoT platform, and must be entered in the format of TEST$_UUID. An NB-IoT UE manufacturer can obtain this verification code from the communication interface between an application and the IoT platform.

– Manufacturer Id, Device Type, and Model must be consistent with information on the device profile created on the IoT platform, and such information is provided by the NB-IoT UE manufacturer.

– Protocol Type uses CoAP by default.

4. Click Submit to submit device information. After such information is successfully submitted, information on the added NB-IoT device will be displayed on the Dashboard interface, and the device status will be displayed as Registered.

Fig. 7-4 illustrates device info interface.

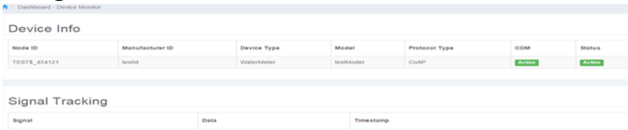

Fig. 7-4 Device Info interface

Information on the Signal Tracking page is the main basis for commissioning using the SoftRadio. During the commissioning, you can check AT commands sent to the SoftRadio from NB-IoT UEs, responses from the SoftRadio to NB-IoT UEs, and requests sent to the IoT platform from the SoftRadio on the Signal Tracking page.

Table I Describe Signaling Tracking Types

TABLE I: DESCRIBING SIGNALING TRACKING TYPES

Type	*Description*
DEV->SR	AT commands sent to the SoftRadio from NB-IoT UEs
SR->DEV	AT command responses sent to NB-IoT UEs from the SoftRadio
SR->IOT	Requests sent to the IoT platform from the SoftRadio
AT_ERROR	AT commands that cannot be identified by the SoftRadio

Typical MO/MT Procedure

Our trial of water meter is used as to introduce the MO/MT procedure. Fig. 7-5 illustrates MO/MT procedure.

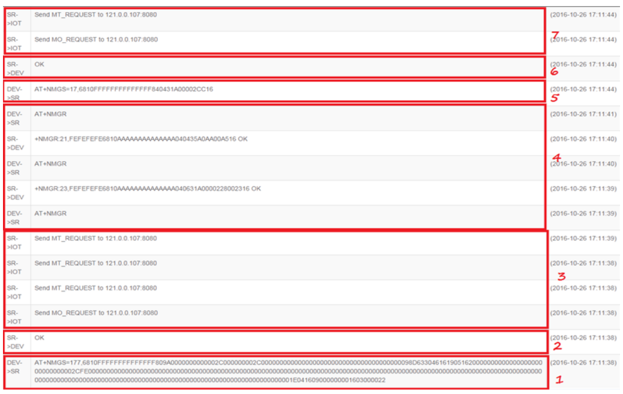

Fig.7-5 MO/MT procedure

The MO/MT procedure is as follows:

1. The water meter sends an AT+NMGS command to request for sending data with the length of 177 to the IoT platform.

2. The SoftRadio verifies data validity after receiving the data and replies OK to the water meter after the verification succeeds.

3. The SoftRadio sends an MO request to the IoT platform. The MO request contains data reported by the water meter. After receiving a response from the IoT platform, the SoftRadio sends multiple MT requests to the IoT platform. The IoT platform replies data to be delivered to the water meter to the SoftRadio. The SoftRadio caches the data.

4. The water meter sends an AT+NMGR command to obtain downlink data stored in the SoftRadio cache. The SoftRadio replies the earliest data with the length of 23 to the water meter in +NMGR mode. The water meter sends an AT+NMGR command again. The SoftRadio replies data with the length of 21 to the water meter. The water meter sends an AT+NMGR command the third time. The SoftRadio does not reply to the water meter because there is no data in the SoftRadio cache.

5. The water meter sends an AT+NMGS command again. The SoftRadio sends data with the length of 17 to the IoT platform.

6. The SoftRadio confirms that the data is valid after receiving the request and replies OK.

7. The SoftRadio sends an MO request to send data to the IoT platform and then sends an MT request to the IoT platform to download data to be delivered to the water meter.

VI. CONCLUSION

This article provides an overview of NB-IoT, eMTC, eMIMO and Massive CA as the main 5G three KPIs (massive IoT connections, low latency and high gigabit throughput) and discusses the RF deployment scenarios of 5G include RF KPI: coverage and capacity. Our commercial trial results show that the targets can be achieved in all deployment scenarios of 5G.

DECLARATIONS SECTION AVAILABILITY OF SUPPORTING DATA

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

COMPETING INTEREST

The authors declare no conflict of interest.

FUNDING

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AUTHORS CONTRIBUTION

A.M., T.M. and N.H. conceived the research and conducted the trials; A.M. designed and implemented the new 5G solution; T.M and N.H analyzed the NB-IoT trial data, results and verified the theory; All authors participated in the writing of the manuscript.

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COMPETING INTEREST

The authors declare no conflict of interest.

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