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SUPPORT OF RESOURSES REDISTRIBUTION IN NB-IOT LTE NETWORKS

Introduction

The world has begun large-scale deployment of 5G generation wireless broadband access networks, developed by 3GPP consortium and called New Radio (NR). However, the rapid development of the concept of IoT has become the reason for the need to provide wireless connectivity a huge number of devices that are not tied to a specific subscriber but are part of the infrastructure. Within the 5G NR standard for such devices, a new type of service is provided, which called massive machine type communication (mMTC) and is focused on optimizing the use of network resources to support a large number of stable connections per unit of area. However, due to the requirements of mobility, extended coverage area, security, diverse QoS, etc., a large percentage of MTCDs will need to connect directly to cellular networks [1].

Machine-to-machine (M2M) is expected to significantly increase in future wireless networks, M2M communications enable direct communication between multiple devices. In recent years, the number of MTC devices has grown tremendously. As one of the most promising technologies for fifth generation (5G) mobile networks, MTC will enable innumerable applications in areas such as smart homes, healthcare, automotive communications, and intelligent cities. For both MTC are primarily characterized by a high device density, a low data rate, an acceptable level of delay tolerance, and high connection/communication frequency.

Improving the transmission link performance

Narrowband Internet of Things (NB-IoT) is an LPWAN protocol standardized by 3GPP that enables a wide range of new IoT devices and services connected to the cellular network [2].

The Internet of Things (IoT) is a global infrastructure for the information society that provides the ability to provide heavier services by connecting (physical and virtual) things to each other based on existing interoperable information and communication technologies. NB-IoT designed for stationary devices with low data transfer and low consumption. Data collection has played a key role throughout the era of the Internet of Things. More and more devices are interconnected, and wireless applications have become the preferred networking solution. A provider of IoT solutions continues to develop a wide range of wireless sensor devices for a variety of applications in order to provide customers with the latest solutions to complement their IoT application systems.

There are obviously many parts in any IoT device: sensors, actuators, boards, antennas, chips, micro-electro-mechanical systems and so forth. The data, which are a result of the sensing and converting of any given state or change of state in temperature, presence of gases, location and so forth usually, go from the sensor hub or IoT gateway to the cloud or a datacenter. However, given the described movement to the edge and the increasing functions of IoT gateways and IoT platforms a lot of IoT data processing and preparation (including analysis) can happen close to the devices (the edge) or in the mentioned gateways and platforms. At the same time, one of the main problems is the problem of traffic control on the radio interface in order to ensure the specified quality standards (QoS) for each service provided to the majority of subscribers, in particular, for those who are in corporate networks.

Telecommunications and information technology are now quickly becoming outdated due to the constant updating of technological solutions. However, thanks to WISE-4000 cloud access, data can be transferred directly to the cloud without using a gateway. Traditional automation architecture and basic data acquisition are no longer sufficient to collect various types of data for various IoT applications, so companies are developing wireless sensor nodes (e.g. Advantech WISE-4000 (WSN), WISE-4000) based on the latest IoT concepts and technologies. and are a ready-to-use cloud reading and writing tool.

The REST communication approach can take advantage of not having to use a lot of bandwidth when transferring data. RESTful web APIs in JSON format makes it easy to integrate data into IoT services and optimize them for use over the Internet. In addition, REST supports HTTPS or TLS, which increase security when publishing or receiving data between devices and the cloud. In addition, it also allows end devices to actively public.

Experts believe that NB-IoT technology will gain popularity among operators, because its maintenance and operation will cost them less than today's advanced LTE and GSM networks [3], this is due to its characteristics.

Massive NB-IoT modules that try to request the radio channel resources at the same time for uplink data transmission may suffer from random access preamble collision. This is caused by several factors such as detection inaccuracy that may not satisfy the detection threshold, the high probability of false alarm, etc. Several works have proposed random access preamble detection algorithms (i.e., random access with differential barring etc.) and others have developed mathematical models to characterize the preamble transmissions in order to improve the NPRACH success rate and better time-of-arrival estimation and other NPRACH performance improvements. However, it is still unclear which scheme is effective for massive deployment, since most of the proposed schemes do not consider the heterogeneous network architecture, channel estimation impairments, or realistic channel conditions [3,4].

An IoT module is a small electronic device embedded in objects, machines, and things connected to wireless networks and sends and receives data. IoT modules and IoT terminals use a variety of wireless technologies to stay seamlessly and securely connected.

These range for:

- 5G, 4G, and 3G cellular solutions for high bandwidth applications like connected cars,
- Low-Power, Wide-Area (LPWAN) solutions such as MTC (Machine Type Communication),
- Bluetooth and LoRa are used for intelligent road systems, smart city applications, and enterprise applications.

Selecting the IoT RF module with the best features, bandwidth, and price point for each use case is an essential step toward achieving business and revenue goals.

These embedded modules dramatically shorten the development time required to complete sophisticated IoT, Industrial Internet of Things (IIoT), and automation projects. To succeed, organizations must have highly developed data and analytics practices, robust operational technologies and agile chops, as well as the ability to navigate change. Tibbo's IoT module lineup includes the WM2000 featuring an integrated Wi-Fi interface.

The problem is, most IoT solutions don't need the sizzling speed and broad bandwidth of 4G. It doesn't make sense to pay for 4G when 2G capabilities are necessary. 4G mobile network can become an LPWAN (Low Power Wide Area Networks) network with a simple software upgrade. LPWAN can connect a vast sea of IoT objects, improving safety, efficiency, and resource management by delivering on the 3C's of IoT applications:

1) Cost: LPWAN is to cut more than 50% of the cost compared to broadband LTE.
2) More than 100x lower power than broadband LTE.
3) Coverage: 5x greater coverage than broadband LTE in terms of gain.

IoT LTE modules based on optimized "categories" of LPWAN 4G cellular technologies (LTE Cat 1, Cat M, Cat NB-IoT) drive significant cost savings, efficiency, and device simplicity compared to broadband LTE. Cat 1, Cat M and Cat NB-IoT LTE modules allow highly efficient use of the current LTE spectrum requiring far less power and delivering the connectivity necessary for most IoT applications.

Also, LPWAN LTE modules are much less complicated, allowing for cost-efficient design and they offer longer-range connectivity with in-depth coverage. Choosing the right IoT wireless module will ease development, speed up time to market, and ultimately improve ROI.

Mathematical model of processing traffic intensity of macro - and microcells in NB-IoT LTE network

Programmable modules Internet of Things (IoT) are highly integrated, compact embedded devices with integrated Ethernet or Wi-Fi that serve as the foundation of own hardware solutions. IoT solution design, consideration must be given to determine the necessary features. Still, it's only possible with pervasive IoT solutions built on flexible and long-lived wireless connectivity. At the heart of it all is a tiny device called the IoT module responsible for connecting virtually anything to wireless networks. IoT Modules come with a wide range of wireless technology standards, and they provide a variety of features that can impact the success of IoT applications.

Propose to expand the capabilities of the programmable IoT module, using a mathematical model describing a of a cluster of macro- and microcells with NB-IoT LTE network services.

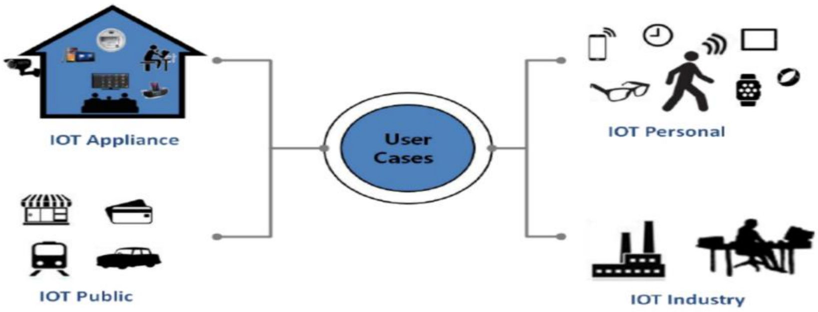

Fig. 1 Model of implementation of NB-IoT LTE services

The NB-IoT LTE standard can deployed in three versions:

– autonomous (standalone);
– on the guard-band;
– in-band.

The most common is in-band, it is widely used, where NB-IoT in-band networks are deployed by telecommunications companies Vodafone, Deutsche Telekom, Telecom Italia Mobile and others.

Mobile LTE networks involve a hierarchical organization of cells, which improves service quality and increases the efficiency of bandwidth use [6]. Will to analyze the bandwidth of a fragment of the hierarchical mobile network.

Services providers (SPs) in LTE systems are enduring many challenges in order to accommodate the rapid expansion of mobile data usage.

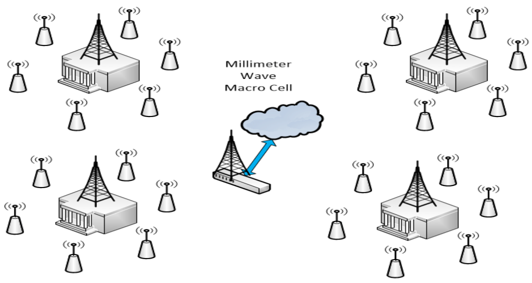

Fig. 2. LTE wo-tier cellular network topology

At the same time, Narrowband refers to NB-IoT's bandwidth of maximum 200 kHz thanks to which it can coexist either in the Global System for Mobile Communications (GSM) spectrum or by occupying one of the legacy LTE Physical Resource Blocks (PRBs) as in-band or as guard-band. Since it coexists in the LTE spectrum, NB-IoT follows the legacy LTE numerologies as it uses OFDM) and SC-FDMA) in the downlink and uplink transmission schemes, respectively. Some modifications in the physical (PHY) and medium access control (MAC) layers are implemented to support the long-range massive machine-type (mMTC) connections with low power, low data rates, low complexity, and hence low cost. However, despite its low complexity, this new radio access technology (RAT) delivers better performance in terms of the supported number of devices, and coverage enhancements for latency-insensitive applications with maximum coupling loss (MCL) of about 20 dB higher than LTE (i.e., 164 dB) [5, 6].

Let's see number of massive of device support in a cell in consideration.

As per the IoT requirements, there will be huge number of connected devices supporting different applications. NB-LTE needs to support this massive IoT capacity by using only one PRB in both uplink and downlink. NB-LTE with one PRB supports more than 52500 UEs per cell.

Inter-site distance (ISD) = 1732m

Cell site sector radius, *R = ISD/3 = 577.3m*

Acs- area of cell site sector (assuming a regular hexagon)

*Acs =3*sqrt(3/2)*R^2 = 0.866 sq km*

Hd -household density per sq km , Hd =1517

Nh-number of devices within a household, Nh =40

Ncs -number of devices per cell site sector

*Ncs = Acs * Hd * Nh = 0.866*1517*40= 52549 user/cell site.*

There is no establishment cause for delay tolerant traffic, because in NB-LTE all traffic is assumed to be delay tolerant. The high concentration of users in the cell radius requires an increase in cell bandwidth in conditions of high concentration of users of intelligent services NB-LTE network.

3GPP combines a variety of mobile technologies - from corporate picocell structures housed inside buildings to global satellite coverage. Thus, we can talk about the hierarchical structure of 3G networks. Pico and microcells are designed to serve slow-moving subscribers, while macrocells and satellite coverage areas are designed to serve subscribers at high and very high speeds. Microcells and macrocells mean the structural elements of neighboring levels in the hierarchy of the LTE mobile network, microcells are macrocells with respect to the picocell, which is a LTE microcell with respect to it. Subscribers divided by types of speed: fast, served by macrocells, and slow, served by microcells. For the design of hierarchical mobile networks, several templates use is the division of the network into clusters of cells and covering each cluster with one macrocell. In addition to serving NB IoT LTE users with different speed characteristics, the macrocell can also act as an additional resource in relation to the microcells. This means that if the microcell lacks channels to service incoming calls (new or transferred from anather microcells in the handover process), it can transfer the incoming call for service to the macrocell. This technology allows to quickly be responding to changes in subscriber load in the coverage area of the macrocell.

When using a macrocell as a resource that can shared, the access policy that most closely matches the dynamics of the change in the load on the microcells should apply. The macro cell can also be a dedicated resource, ie it may not serve fast moving subscribers, but only provide its own channels to service calls blocked in microcells. It is clear that the most efficient use of macrocell capacity to service subscriber calls is provided by using the capacity of the microcells themselves, when the free capacity of the macrocell remains maximum. To do this, the method of repackaging channels used, i.e. channels occupied by calls from subscribers of each microcell in the macrocell are pulled back into the microcell when one of its channels is released.

For evaluation of the change in the throughput of NB IoT LTE depending traffic intensity of macro- and microcells in NB-IoT LTE network proposed following mathematical model.

Consider a cluster of a two-tier LTE network consisting of *M* microcells and one macrocell

(fig.2). The macrocell covers all M microcells. Microcell k has c_k communication channels for servicing subscriber calls, $k = \overline{1, M}$.

Subscriber calls occur in microcells *k* with intensity λ_k. and disappear (either at the end of the call, or when transferring a call to one of the neighboring cells) with intensity, $\mu_i \theta_{ji}$.

The end of the conversation in the k -th microcell occurs with probability P. The subscriber who leaves the service area of $\mu_i \theta_{ji}$. the microcell k, with probability moves to the service area of $\mu_i \theta_{ji}$the microcell $j, j = \overline{2, M}$. A macrocell has C communication channels that are used by microcells to service incoming calls if all of the microcell's own channels are busy,is using C channels by macrocells of a two-tier LTE network cluster. The network of the k-th microcell is bounded by the threshold r_k, $k = \overline{1, M}$ A call that cannot be received due to the lack of channels in the corresponding microcell and in the macrocell is lost, and its impact on the call flow is not taken into account. When one of the channels is released into the microcells, the channels are repackaged with some intensity. To describe in the framework of the proposed model of calls coming from fast-moving subscribers directly to the macro cell, can put:

$$c_1 = 0, r_1 = C, \theta_{1j} = 0, \theta_{j1} = 0,$$

$j = \overline{2, M}$.

Figure 3 shows macro-and microcells NB-IoT LTE network of traffic intensity model.

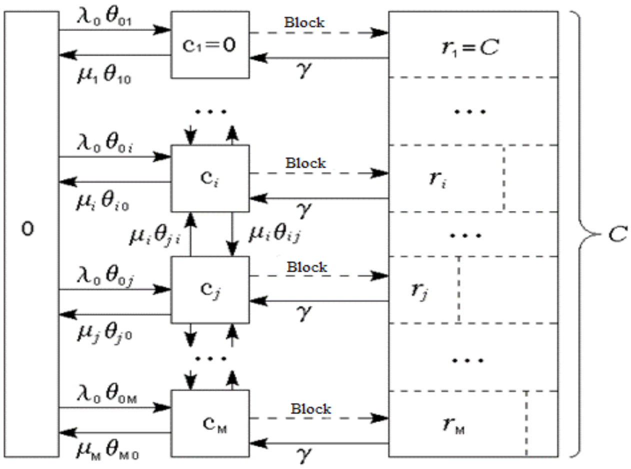

Fig. 3. A model describing of macro-and microcells NB-IoT LTE network traffic intensity

In this case determine $\lambda_0\theta_{01}$ and $\mu_1\theta_{10}$, respectively, the intensity of access to the macro cell and the intensity of service calls from fast-moving subscribers. Note that such a change means a decrease per unit number of microcells covered by the macrocell. The accepted model assumes that the average duration of a conversation in different microcells is different.

This allows can to flexibly describe the operating conditions of the simulated NB-IoTLTE network. For the case of instantaneous repackaging of channels ($y < \infty$), the state space of the Markov process, which describes the operation of the system, has the form:

$$S := \left\{ n = (n_1, ..., n_m) : 0 \le n \le c + r, \sum_{k=1}^{M} (n_k - c_k)^+ \le C \right\}, \tag{1}$$

where $(x)^+ = \begin{cases} x, x \ge 0, \\ 0, x \prec 0. \end{cases}$

Can introduce the indicator function

$$x(n) = \begin{cases} 1, n \in S \\ 0, n \notin S \end{cases}$$

and $e_k := (I)_k$ – the k -th column of a unit matrix of dimension M.

Let's mark $\overrightarrow{\lambda_o} := (\lambda_0\theta_{01}, \dots, \lambda_0\theta_{0M})$, let $\overrightarrow{\lambda} = (\lambda_1, \dots, \lambda_M)$- solution of the equation, $\overrightarrow{\lambda}^T (E - \Theta) = \overrightarrow{\lambda_0^T}$, where $[\Theta]_{ij} := \theta_{ij}, i, j = \overline{1, M}$.

With some additional limitations, the described system has a convenient for analysis multiplicative solution [7]:

$$p(n) = G \prod_{k=1}^{M} \frac{p_k^{n_k}}{n_k!},\ p_k = \frac{\lambda_k}{\mu_k},\ k = \overline{1, M},\ G = \left(\sum_{n \in S} \prod_{k=1}^{M} \frac{p_k^{n_k}}{n_k!} \right)^{-1}. \tag{2}$$

For $y = \infty$, well-known algorithms based on recursion or convolution can be used [8]. Consider the case of non-instantaneous repackaging of channels, when $y < \infty$.

Can introduce a random variable $X_{k1}(t), t \geq 0$ - the number of calls served by the microcell k at time t, and a random variable $X_{k1}(t), t \geq \theta$ - number of calls related to the microcell k, which at time - t is served by the macrocell, $k = \overline{1, M}$.

The operation of the system in this case can be described by a Markov process of dimension 2M. The process state space X (t) has the form:

$$S := \{n = (n_{10},...,n_{M0}, n_{11},...,n_{M1}\}: n_{k0} \leq c_k,\ n_{k1} \leq r_k,\ k = \overline{1,M}\ ,\ \sum_{k=1}^{M} n_{k1} \leq C \quad (3)$$

To analyze the proposed model $y < \infty$, the theory of overload and the method of equivalent substitutions can used [9, 10].

The numerical analysis of the presented model for $y = \infty$ and $y = 0$ is performed below.

For considered a cluster of a two-tier mobile network (fig. 2): microcells - regular hexagons inscribed in a circle with a radius of 425 m; the radius of the macrocell is 1275 m.

The intensity of calls in each microcell per unit area is a in the macrocell: $1{,}5 \cdot 10^{-6}\ 1/s \cdot м^2\ \left(\lambda_{0i} = 0{,}8541/s, i = \overline{2{,}8}\right)$, of fast-moving subscribers - $10^{-7}\ 1/s \cdot м^2\ \left(\lambda_{0i} = 0{,}5251/s, i = \overline{2{,}8}\right)$, average talk time – 100s.

Each microcell has 8 channels for handling incoming calls. When using macrocell channels, there is a complete sharing policy, where $r_i = C, i = \overline{1{,}8}$.

According to the model there is a linear increase in throughput depending on the capacity of the macrocell C when using the general resource of the macrocell for a microcell of equal size without prior repacking of channels when servicing moving subscribers. Microcells have a uniform input load, so the intensity of occupancy of macrocell channels by calls belonging to different microcells is the same, i.e. an increase in the capacitance of a macrocell along the C-channels is equivalent to an increase in the capacitance of each microcell along the [C/M] channels. Channel repacking technology significantly increases system throughput. In the absence of moving subscribers and C=4, servicing of an additional load of 7 Earl is provided. That is, the efficiency of using a macrocell increases almost 3 times.

Cell selection and mobility procedure of macro and microcells NB-IoT LTE of cluster

NB-IoT LTE network is designed for infrequent and few byte data transmission between the UE and the network. It is assumed that the UE can exchange this information while being served from one cell, therefore, a handover procedure during RRC_CONNECTED is not needed. If such scenario a cell change would be required the UE has first go to the RRC IDLE state and re-select another cell there in.

For the RRC_IDLE state, cell re-selection is defined for both, intra frequency and inter frequency cells. Inter frequency refers here to the 180 KHz carrier, which means that even if two carriers are used in the in-band operation embedded into the same LTE carrier, this is still referred to as an inter-frequency re-selection. In order to find a suitable cell, the UE first measures the received power and quality of the NRS. These values are then compared to cell specific thresholds provided by the NB-SIB.

The S-criteria states that if both values are above these thresholds, the UE considers itself to be in coverage of that cell. If the UE is in coverage of one cell, it camps on it. Depending on the received NRS power, the UE may have to start a cell re-selection. The UE compares this power to a re-selection threshold, which may be different for the intra-frequency and the inter-frequency case. All required parameters are received from the actual serving cell, there is no need to read NB-SIBs from neighbors' cells. If multiple cell fulfill the S-criteria, the UE ranks the cells with respect to the power excess over another threshold. A hysteresis is added in order to prevent too frequent cell reselection.

Unlike conventional LTE, there are no priorities for the different frequencies. The UE finally selects the highest ranked cell, which is suitable, i.e. from which it may receive normal service. When the UE leaves RRC_CONNECTED, it does not necessarily select the same carrier to find a cell to camp on. The RRC Connection Release message may indicate the frequency on which the UE first tries to find a suitable cell. Only if the UE does not find a suitable cell on this frequency, it may also try to find one on different frequencies.

Conclusions

Has been analysis of Narrowband Internet of Things (NB-IoT) which allows enables a wide range of new IoT devices and services connected to the cellular network. Is shown then, NB-IoT is designed for fixed devices with low data transmission, low consumption, which leads to an increase in the number of devices connecting to each other. In turn, the massive NB-IoT modules that attempt to simultaneously request radio channel resources for uplink data transmission may suffer from random access preamble collision.

An increase in the efficiency of using the bandwidth of networks based on macro- and microcells with a high concentration of users of NB-IoT LTE networks is shown.

The results of a numerical analysis are presented to identify the factors affecting the system performance.

There is a linear increase in throughput depending on the capacity of the macrocell C when using the general resource of the macrocell for a microcell of equal size without prior repacking of channels when servicing moving subscribers, channel repacking significantly increases system throughput. In the absence of moving subscribers servicing of an additional load is provided, the efficiency of using a macrocell increases almost 3 times.

NB-IoT development will continue and will be expanded to include positioning methods, multicast services such as software updates or group-wide messages, mobility and service continuity, and additional technical details to expand the scope of NB-IoT technology.

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