Multi-User Scheduling for Narrow Band Internet of Things

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***Abstract*—In this paper, we investigate the performance issue of massive Internet of Things (IoT) by evaluating to what extent the number of devices can be accommodated. We build a system level simulator based on the 3GPP TR 45.820 Narrow-Band IoT standard. We find that the current First In First Out (FIFO) approach can serve 630 devices per base station assuming that one device can be served at a time. Then, we develop the scheduling techniques - maximal delay tolerance and α-maximum tolerance for a system-level performance analysis. Our experiment results show that the proposed scheduling techniques outperform at least 2.8 times compared with the FIFO policy.**

Keywords–NB-IoT; Scheduling; Resource allocation.

I. INTRODUCTION

The Internet of Things (IoT) aims to enable all devices (i.e., electronics, transportation, sensors and home appliances) to communicate to each other without requiring human or computer interactions. By analyzing and exchanging the collected data from these IoT devices, various services can be integrated and be leveraged with each other to improve user experiences. The Fifth Generation (5G) communications systems provide faster speed and higher capacity than current 4G systems. Therefore, the IoT market is expected to have 30 billion connected devices by 2025 [1].

Low-Power Wide-Area Network (LPWAN) is one of the wireless communications for massive IoT devices. Some technologies, such as Long Range Wide Area Network (LoRaWAN), Sigfox and NB-IoT are designed to support a long range service for the devices subject to the constraint of battery life. However, LoRaWAN and Sigfox are proprietary product. Any non-mobile operator customers can utilize them to deploy the private network on the unlicensed frequency band. Therefore, these two technologies are suitable for the uncentralized local deployment. To completely realize the scenario of everything connected, we need the centralized signaling control to manage the data collected by the sensor. Therefore, the Narrowband IoT (NB-IoT), which is a cellular IoT, is proposed by the 3rd Generation Partnership Project (3GPP) [2]. It follows the LTE standards to design some part of the new specification for NB-IoT. In this way, the NB-IoT can be integrated in the existing LTE specifications [3] to coexist with the LTE system. The technical details tightly related to the LTE specifications are presented by Rohde & Schwarz [4]. In [5], the authors have evaluated and analyzed that the NB-IoT system can provide the extended coverage of 20 dB. The device and network requirements of the NB-IoT system are listed as follows:

- Extreme low data rate support $\sim$ few kbps
- Long delay tolerance $<$ 10s
- Ultra-low complexity
- Long Battery Life $>$ 10 years
- Low Cost $<$ 5 USD
- High Cell Capacity $\sim$ 52k user/cell site
- Extended Coverage link budget $\sim$ 164 dB Maximum Coupling Loss (MCL)
- Low Deployment and Operation Cost
- Consistent and Meaningful User Experience

The authors in [6] have proposed a link-level performance analysis with their inner loop and outer loop algorithms. However, the system-level performance have not been developed to evaluate the NB-IoT system before we deploy it. Additionally, the cell capacity for NB-IoT is still an open issue. Because the feature of repetitions for data and control signaling in NB-IoT, repeating data transmission will decrease the system capacity and even reduce the number of served UEs.

However, the frame structure in the uplink is different from the legacy LTE. A new Resource Unit (RU) is designed for NB-IoT. Besides, the scheduling delay is required in the data transmission because of the ultra-low complexity for NB-IoT devices. It does not consider for scheduling in the LTE system. Therefore, we build a simulation platform to estimate the total number of scheduled NB-IoT UEs with considerations of both repetition and multiple users subject to the latency requirement.

We propose the scheduling algorithms to observe the impacts of performances metrics (e.g., UE number and system throughput) among different scheduling policy. The scheduling algorithms are briefly summarized in the following.

- Maximum delay tolerance: UE with early-transmitted time is served first based on the maximum delay tolerance.
- α-maximum tolerance: Only consider the data transmission time of UEs is lower than the half of maximum delay tolerance. Policy is same as Maximum delay-tolerance.

The remainder of this paper are organized as follows. Section II presents the two-dimension multi-user scheduling and the proposed scheduling algorithms. In Section III, we introduce the flow chart of the simulator and numerical results are also discussed. Finally, we give our concluding remarks in Section IV.

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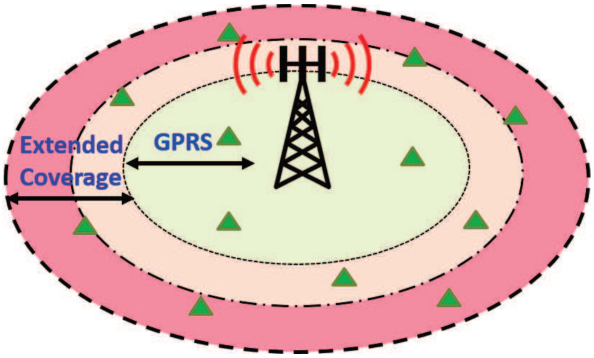


Figure 1. Cell architecture of NB-IoT system.

II. Two-dim Multi-User Scheduling

Consider the uplink transmission of the NB-IoT system, as shown in Figure 1. N uniformly distributed User Equipment (UE) with one omni-direction antenna are served by a base station. The Maximum Coupling Loss (MCL) between the transmitter and the receiver is 164 dB for NB-IoT system, which is 20 dB more than General Packet Radio Service (GPRS).

The piece-wise linear model is adopted for numerical analysis. The path loss model has been defined as follows:

$$P(L)_{dB} = \begin{cases} -K + 10\alpha_1 \log_{10}(d/d_0) & , d_0 \le d \le d_c \\ -K + 10\alpha_1 \log_{10}(d_c/d_0) & \\ \quad + 10\alpha_2 \log_{10}(d/d_c) & , d > d_c \end{cases} \tag{1}$$

where $K = 20\log_{10}\frac{\lambda}{4\pi d_0}$ is a constant path loss factor, d_0 is a reference distance, $d_c = \frac{4\pi h_t h_r}{\lambda}$ is a critical distance, α_1 and α_2 are the path loss exponents depending on the distance from eNB to the specific UE. Note that h_t and h_r are the antenna height of the transmitter and that of the receiver, respectively.

A. SNR-MCS Index Mapping

According to the above propagation model, the Signal-Noise-Ratio (SNR) can be measured at the eNB. For higher transmission efficiency and lower error rate, the eNB indicates the UEs to adapt the Modulation and Coding Scheme (MCS) index based on the corresponding Channel Quality Indicator (CQI). However, there is no CQI reporting for NB-IoT. Thus, we construct the SNR-to-MCS index mapping in Table I.

B. Repetitions Decision

To enhance the coverage performance, a NB-IoT system repeats its transmitted data transmission to combat the signal power attenuation. When the repetition number is doubled, the data rate is halved and the coverage gain is increased by 3 dB. Therefore, we decide the repetition number for the different channel of each UE based on the bit error rate for BPSK or QPSK modulation scheme. The repetition times for the data transmission of UE k can be expressed as follows:

$$r_k = 2^{log_{\sqrt{2}} \frac{Q^{-1}(P_b)}{\sqrt{2\gamma_k}}}, \tag{2}$$

where P_b is a desired target bit error rate, γ_k is the SNR of UE k and $Q^{-1}(\cdot)$ represents the inverse Q function. The maximum repetition times is 2048.

TABLE I. SNR AND MCS INDEX MAPPING

Range of SNR values		MCS index
Lower limit	Upper limit	Value
-5	-4.16	0
-4.16	-3.32	1
-3.32	-2.48	2
-2.48	-1.64	3
-1.64	-0.80	4
-0.80	0.04	5
0.04	0.88	6
0.88	1.72	7
1.72	2.56	8
2.56	3.40	9
3.40	4.24	10
4.24	5.08	11
5.08	5.92	12

TABLE II. MCS INDEX AND SUBFRAME INDEX MAPPING

MCS	I_{SF}							
	0	1	2	3	4	5	6	7
0	16	32	56	88	120	152	208	256
1	24	56	88	144	176	208	256	344
2	32	72	144	176	208	256	328	424
3	40	104	176	208	256	328	440	568
4	56	120	208	256	328	408	552	680
5	72	144	224	328	424	504	680	872
6	88	176	256	392	504	600	808	1000
7	104	224	328	472	584	712	1000	
8	120	256	392	536	680	808		
9	136	296	456	616	776	936		
10	144	328	504	680	872	1000		
11	176	376	584	776	1000			
12	208	440	680	1000				

C. Subframe Index Selection

The BS obtains the MCS index based on the SNR value. Then, the UL data transmission time will be determined by the MCS index and subframe index. The mapping table is listed in Table II defined in [7]. The values in the table indicate that how many packet sizes can be transmitted subject to the MCS and subframe index. The subframe index is selected for the minimum value that greater than transmitted packet sizes corresponding to the MCS index.

D. Scheduling Schemes

For evaluating the total scheduled UEs for NB-IoT system, some scheduling algorithms are employed to allocate the resource to the multiple UEs. We adopt the Minimum Transmission Time (MTT) and First-In First-Out (FIFO) as two basis of the scheduling schemes. The MTT policy means the UEs with the minimum transmission time has higher priority to be scheduled. The FIFO policy let the first-arriving UE will be able to get the best choices. Moreover, we propose two scheduling policies with the consideration of the latency

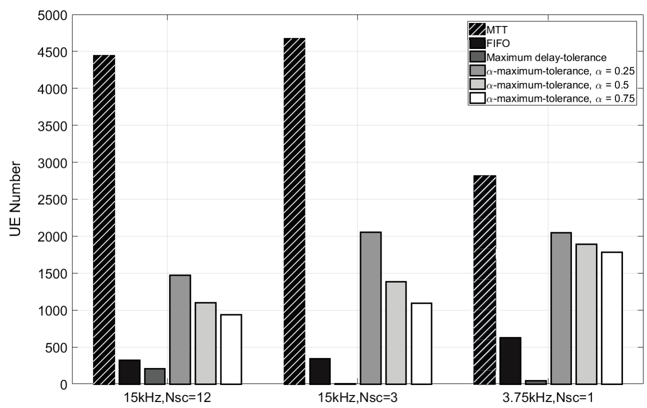


Figure 2. User number of NB-IoT system.

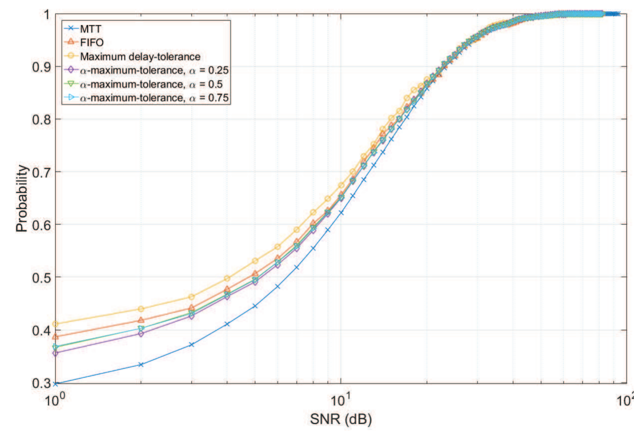


Figure 4. SNR CDF for different scheduling policy.

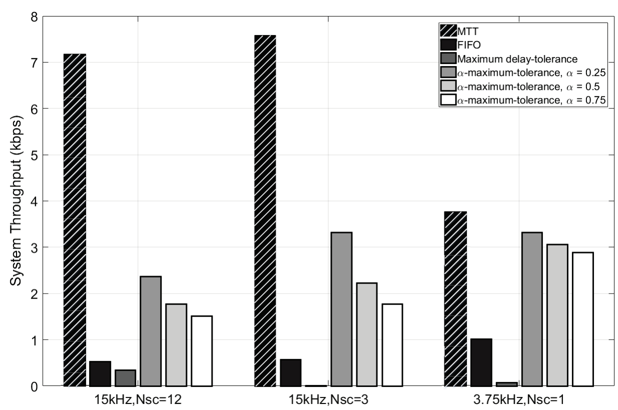
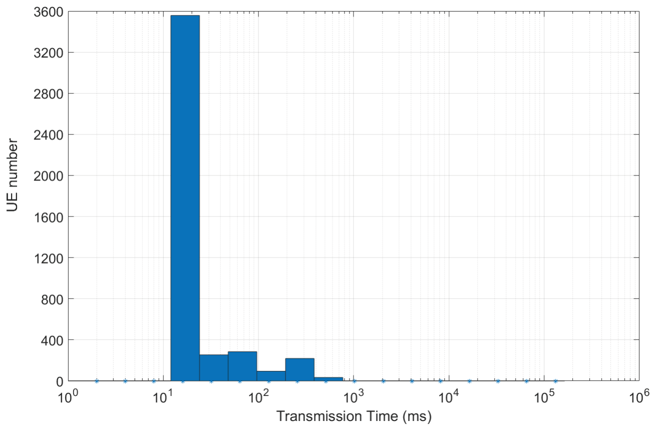


Figure 3. System throughput of NB-IoT system.

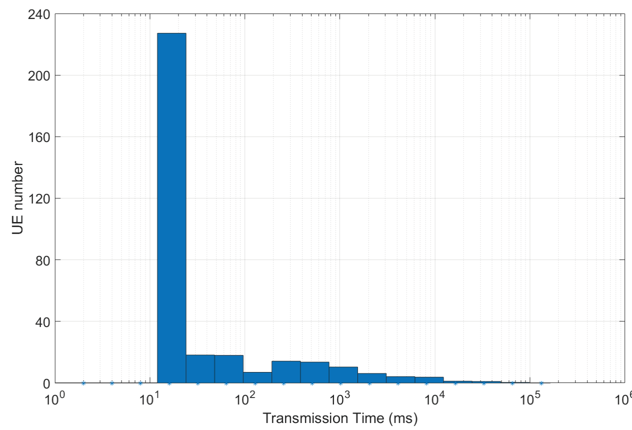
requirement. According to the delay requirement, we obtain the transmitted time point for each of UE in the buffer. As long as the UEs be scheduled before that time point, the delay requirement will be satisfied. Therefore, we propose the maximum delay-tolerance policy. The UE with early-transmitted time point is served first based on the maximum delay tolerance (i.e., 10 sec). However, the UEs with long data transmission time dominantly occupy the resource and decrease the system performances of overall throughput and served user number. To further enhance the system performances, we also propose the improved scheduling policy called α-maximum-tolerance. The parameter of α is determined by the ratio of the maximum delay tolerance. Only the data transmission time of UEs lower than the α of the maximum delay tolerance can be scheduled to utilize the resource. We adopt these scheduling policies to evaluate the system performance for the NB-IoT.

III. Numerical Results

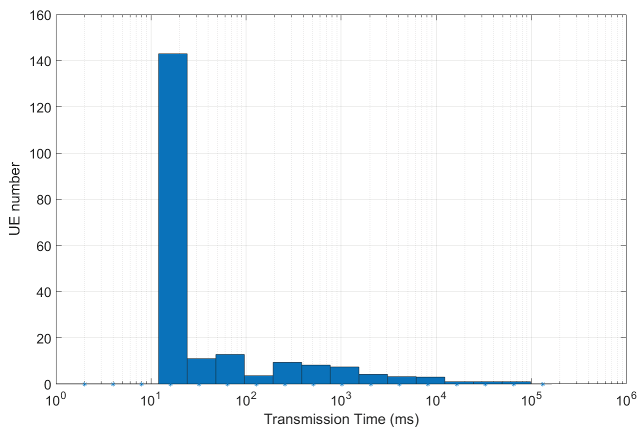
Figure 6 shows the flow chart of our simulator. Table III summarizes the used system parameters [8]–[10]. The UEs are uniformly distributed in a single cell with the desired MCL of 144dB. Only one UE can be scheduled to use the system resource. We assume that all the resources are allocated to the UEs without considering the control signal overhead. The traffic modeladopted in our simulator is the Mobile Autonomous Reporting (MAR) periodic traffic. The packet sizes for the UEs are the random variable of Pareto distribution with the shape parameter $\beta = 1.5$. The minimum and the maximum packet sizes are 20 and 200 bytes, respectively. Additionally, the mapping table and the channel model are mentioned in Section II. Then, we discuss the simulation results of NB-IoT system by using the aforementioned simulation platform. Figure 2 shows the average total number of served UE for MTT, FIFO, maximum delay-tolerance and α-maximum-tolerance with $\alpha = 0.25, 0.5$, and 0.75 scheduling policies. The maximum number of the served UEs for these policies are 4,746, 630, 208, 2.054, 1,894 and 1,788, respectively. For MTT policy, the short-transmission-time UE numbers are more than the long-transmission-time UE numbers as shown in Figure 5(a). Although the long-transmission-time UE is not many, the inner repetition for the UL transmission quality results in more resource utilization. Type-2 RU has less subcarriers than Type-1 RU. When Type-2 RU is adopted, the higher MCS level is selected. Besides, both the repetition and the inner repetition numbers will decrease , thereby freeing the resources to serve other UEs. However, once the band is narrow enough with the better channel condition, using Type-3 RU is unnecessary The frame structure of ype-3 RU is a long length of 8 ms time duration. Thus, the UE numbers decreases as the Type-3 RU is used for the MTT policy. On the contrary, the long-transmission-time UE has higher probability to be allocated the resources as shown in Figure 5(b) for the FIFO policy. In this way, the total UE number for FIFO is 10 times lower than that for MTT. Also, the advantage of Type-2 RU is canceled by them. When the Type-3 RU is used, the bandwidth is so narrow that it provides the higher power spectrum density (PSD) gain with same UL transmit power. Then, the total served UE number increases a little bit. Other policies are all delay awareness according to the different levels of the delay tolerance. Based on the differences of these levels, the proportion of the long-transmission-time UE are diverse as shown in Figure 5(c) and (d). Moreover, that results in variations of the total served UE numbers for distinct RU types. The average system throughput for the MTT, FIFO and proposed policies are shown in Figure 3. Because of the low packet size for NB-IoT devices, the system throughput is no more than 10 kbps. Figure 4 shows the CDF of SNR for the



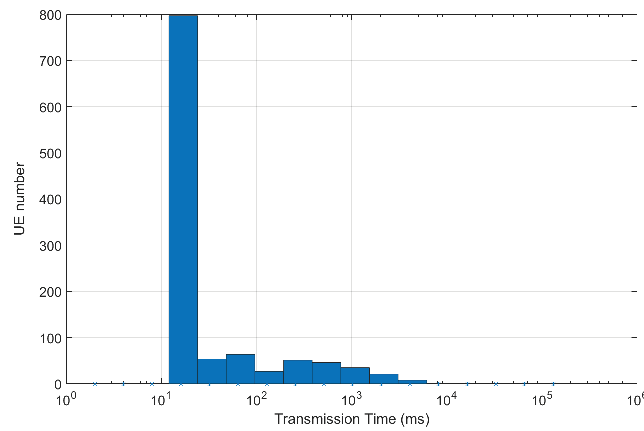
(a) MTT



(b) FIFO



(c) Maximum delay tolerance



(d) α-maximum-tolerance, α = 0.5

Figure 5. Transmission time distribution.

TABLE III. SIMULATION PARAMETERS

Carrier Frequency	900 MHz
System Bandwidth	200 kHz
BS Transmit Power	24 dBm
UE Transmit Power	23 dBm
Noise Figure	3 dB
BS Height	25 m
UE Height	1.5 m
Subcarrier Spacing	{3.75, 15} kHz
Number of Sub-carriers	{1, 3, 6, 12} for 15 kHz SCS {1} for 3.75 kHz SCS
Shadowing Deivation	8 dB
Total Number of UEs	5000

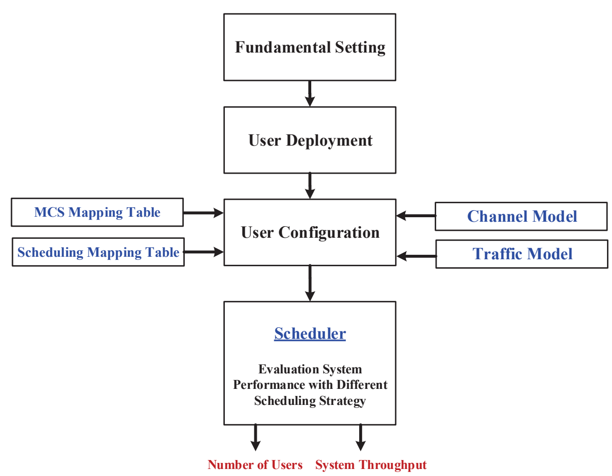


Figure 6. Flow chart of simulation platform.

served UE. We observe that the MTT policy is unfair for the UEs located at the worse environment, i.e., basement or the cell edge. These UEs have no opportunity to be served. On the other hand, UEs at the cell edge can also be served in the FIFO and proposed policies.

IV. CONCLUSION

In this paper, we have developed a simulator to evaluate the system-level performance for the NB-IoT system from the viewpoints of latency awareness. We consider the features of the repetition with the multiple user uplink scheduling. The MTT policy is the best method for the UEs located in the cell

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center. However, the NB-IoT devices deployed at the cell edge cannot be served. To overcome that problem, we propose the fairness and the delay-aware methodology. The performance of the total served UEs for the proposed maximum delay-tolerance policy is worse than the FIFO method due to the consideration of latency limitation. To improve that problem, we further propose the α-maximum-tolerance policy. With adjusting the parameter α, the delay tolerance level will be changed to satisfy the devices requirements. Our experimental results show that the total scheduled UEs for the improved policy have been raised to 2.8$\sim$3.26 times as compared with the FIFO. Our proposed method of the α-maximum-tolerance can provide a fairer way to schedule the UEs. Therefore, the system-level simulator with the proposed scheduling policies provide the preliminary methodology to evaluate the capacity performance for the NB-IoT system.

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