Differentiated Service for Distributed Queuing MAC Protocol in 5G cellular IoT Networks

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***Abstract*—A distributed-queuing medium access control protocol was proposed based on a differentiated service (DSMAC) for 5G cellular IoT networks. In the proposed DSMAC protocol, IoT nodes selected a specified time slot based on the differentiated service and then sent information on the data request control frame to the IoT head in the contention window. The time slot in the contention window was divided based on differentiated service levels according to the priority of data to be transmitted. The proposed DSMAC protocol reduced collision probability and the medium access control (MAC) delay caused by the differentiated data transmission. Furthermore, high throughput was achieved owing to distributed queuing based on the differentiated data transmission mechanism. A comparison of the proposed DSMAC protocol with traditional distributed-queuing MAC protocols revealed that the DSMAC protocol performed better in 5G cellular IoT networks.**

Keywords—Internet of Things, differentiated service, medium access control, distributed queuing, 5G

I. Introduction

The Internet of Things (IoT) uses a global network wherein all devices with unique addresses are interconnected. The IoT allows anyone and anything to communicate with one another at any time and place through networks or services [1]. The continuous decline in the cost of communication has accelerated the development of wireless devices that support the ubiquitous IoT. The major challenges for wireless devices in the IoT are the limitations in mobile device battery energy and lack of spectrum due to increased communication with IoT objects and cloud platforms. The cellular structure is essential for wide-area IoT communications. However, challenges in cellular IoT communication persist such as propagation delay and spectrum scarcity [2,3]. The IoT brings a revolutionary breakthrough in terms of data transmission rates, propagation delay, connectivity for large devices, and network reliability [4].

Thousands of IoT objects are deployed in wide-area IoT applications. However, the aggregate traffic of IoT objects is not high enough to locate the resources of cellular networks [5]. The 5G cellular IoT is designed to meet the requirements of high data transmission rates applications such as audiovisual data transmission, while the 5G cellular IoT is characterized by low complexity and cost. Therefore, the challenges in the machine-to-machine (M2M) communication design differ from those of conventional broadband networks [6].

The 5G cellular IoT shows high throughput and low power consumption in the transmission between cellular phones. Different connections of 5G cellular IoT use the same spectrum without any interference [3]. Therefore, 5G cellular IoT is a feasible method for supporting massive M2M wireless communications [7].

This study was carried out to design a distinct mechanism for appropriate IoT systems to enhance time-slot efficiency in using the spectrum of the IoT network. The main contributions of the proposed differentiated service MAC (DSMAC) for distributed queuing protocol are as follows.

- To enhance the system efficiency of the 5G cellular IoT
- To reduce the collision probability of MAC contention in distributed queuing MAC protocols of 5G cellular Io.
- To decrease contention delay

The remaining parts of this article are as follows. The existing MAC protocols for IoT networks are introduced in Section II. Section III introduces the system model of 5G cellular IoT. Performance evaluation is discussed in Section IV, and Section V concludes this article.

II. Related Work

Distributed queues are characterized by stable performance, near-optimal channel utilization, latency, and energy consumption for data transmission. The distributed queue includes two queues: the contention resolution queue (CRQ) and the data transmission queue (DTQ). All nodes that collide enter the competition resolution queue, and the successful nodes enter the data transfer queue [8].

The collision problem that persists in the TDMA MAC protocol becomes complicated, especially when the traffic increases. A distributed queuing random-access MAC protocol was proposed to solve the collision problem [9]. The DQ mechanism with three slots in the contention period achieved the highest throughput compared with other mechanisms, having different numbers of slots [10]. An extended distributed queuing random access protocol (DQRAP) can be used in wired and central infrastructure networks, as proposed [11]. In Ref. [12], a combined method of DQRAP and code division multiple access (CDMA), called DQRAP/CDMA, was proposed. This combined method used in 3G cellular networks improved the random-access throughput, throughput stability, and transmission delay. The DQRAP/CDMA stopped the traffic input when the traffic simultaneously reached the upper load limit in multiple transmissions. This enabled the system to achieve stable throughput by reducing the collision problem.

Another study proposed a differential quality of service (QoS) DQRAP [13]. The various differential services were satisfied by the cross-layer design of the physical and MAC layers. The priority of the service was determined by the priority of the transmission, channel status, and MAC queuing delay. Therefore, this improved system throughput and transmission delay.

In this study, we proposed novel concepts using the DSMAC protocol for 5G cellular IoT networks. The spectral efficiency of 5G cellular IoT networks was improved by using a differentiated service mechanism for data transmission. Second, reducing the data transmission latency through the DSMAC protocol under differentiated data transmission.

III. System Model

Figure 1 shows the architecture of the proposed 5G cellular IoT network. An IoT network opportunistically used the idle spectrum of a cellular network by employing cognitive radio technology. The proposed 5G cellular IoT network operated the time slot division mode to synchronously access the spectrum using the transmission time interval structure of the cellular network while the spectrum is idle [14].

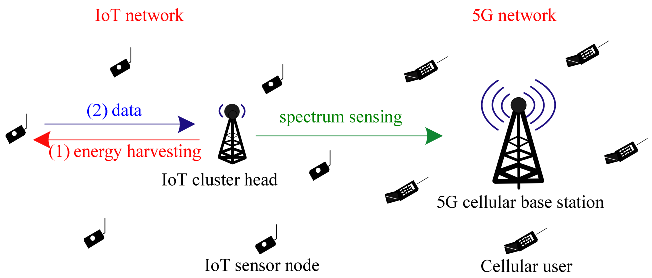

Fig. 1. Architecture of 5G cellular IoT networks.

Two node types exist in a 5G cellular IoT network: cluster head and cluster member. In the proposed DSMAC protocol, the cluster head was responsible for scheduling the transmissions of the cluster members. The cluster head scheduled one data channel for the SU-connection pair based on the outcome of the sensing period. The procedures for differentiating services in 5G cellular IoT networks were as follows. First, the cluster head of the IoT network sensed the spectrum of the cellular network and accessed the optimum idle spectrum. Second, the cluster member performed a differentiated service using the cluster head.

The system time was divided into beacon intervals consisting of two periods: sensing and contention. Each contention period has slots for data requests (REQ). After the data request, the cluster head differentiates the service and data confirmation frame from all members in the cluster, and the data transmission was permitted for successful nodes. The duration of the beacon interval was chosen to maintain the interference within a tolerable range of primary users (PUs).

IV. Performance Evaluation of 5G Cellular IoT Networks

The system performance was evaluated for the proposed DSMAC-based system in 5G cellular IoT networks. The main difference between the DSMAC and traditional distributed queuing MAC was the differentiated service. In DSMAC, the slot selection for the MAC contention period was determined by a differentiated service. However, the traditional distributed queuing MAC protocol randomly selected REQ slots. DSMAC dynamically selected a slot according to the differentiated service. Therefore, we compared the system performance of DSMAC with the traditional distributed queuing MAC scheme. The parameters of the proposed DSMAC are summarized in Table I.

TABLE I. Parameters for Proposed DSMAC Scheme

Simulation time	10000 s
Number of nodes	3, 4, 5, 10, 20
Number of time slots per each contention period	2,3, …, 50
Bounded region	600 m X 600 m

Here, the throughput and delay were taken as performance evaluation metrics.

A. Throughput

The system performance of IEEE 802.11 was evaluated by the method proposed by Ref. [15]. The system throughput ζ for 5G cellular IoT networks was defined as follows.

$$\zeta = \frac{R_{data} T_{suc}}{T_{simu}} \tag{1}$$

where R_{data} is the transmission rate for a data channel, T_{suc} is the sum of the successful transmission times for all IoT nodes, and T_{simu} is the simulation time [15].

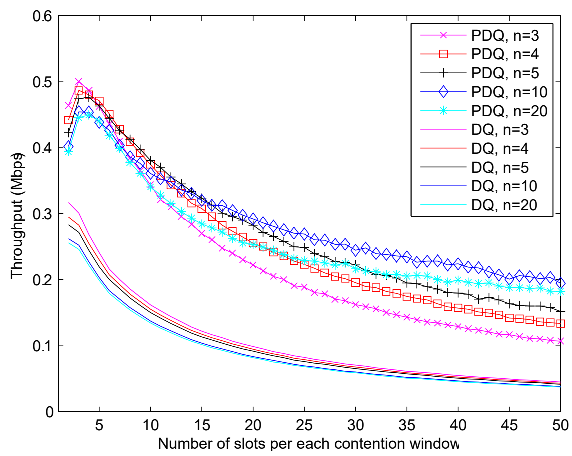

Fig. 2. System throughput in 5G cellular IoT networks.

Figure 2 shows the system throughput of DSMAC compared with the traditional distributed queuing MAC in 5G cellular IoT networks. The system throughput in DSMAC under 3 nodes ranged from 0.50 to 0.11 Mbps for 3 and 50 time slots for each contention period. Under the same conditions, the system throughput in traditional DQMAC ranged from 0.32 to 0.062 Mbps. DSMAC provided the largest improvement (77.4%) in system throughput with the traditional distributed queuing MAC in 5G cellular IoT networks.

B. *Delay for Collision Resolution Queue*

The packet delay for MAC contention in the proposed DSMAC was the time for the collision resolution queue, given as follows.

$$T_{delay} = T_{CRQ} \tag{2}$$

where T_{CRQ} is the average number of collisions in the MAC contention period for DSMAC in the traditional distributed queuing MAC protocol.

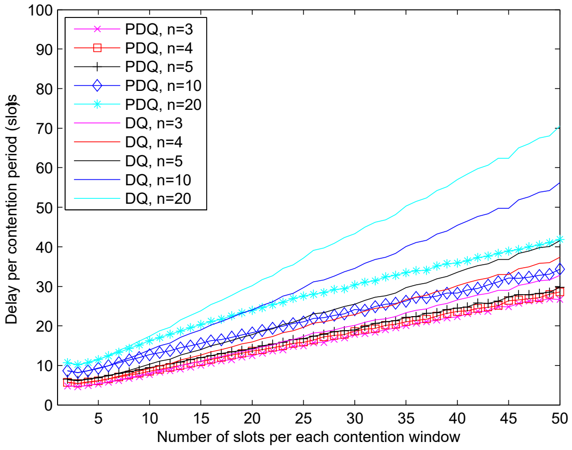

Fig. 3. Packet delay in 5G cellular IoT networks.

Figure 3 shows the contention delay in the traditional distributed queuing MAC and DSMAC in 5G cellular IoT networks. The length of the contention period indicates the total number of time slots for all contention nodes required for the successful transmission of data packets. The contention delay in DSMAC under 3 nodes ranged from 4.82 to 26.69 time slots, whereas in the traditional distributed queuing MAC, it ranged from 4.82 to 32.82 time slots. DSMAC showed the largest improvement (22.9%) in contention delay compared with the traditional distributed queuing MAC in 5G cellular IoT networks. MAC collisions occurring in DQMAC were more serious than those in DSMAC because a priority mechanism was lacking. Therefore, DSMAC had a higher throughput and lower delay per contention period than the traditional DQMAC.

V. Conclusions

High system throughput and low contention delay were achieved using the proposed differentiated service distributed queuing MAC protocol. The contention delay reduction in DSMAC was greater than that in traditional distributed queuing MAC because the idle slots were saved by the differentiated service in DSMAC. The contention collision rate for DSMAC was lower than that for the traditional distributed queuing MAC. Consequently, high system throughput and low contention delay were achieved in DSMAC using differentiated services. The simulation results showed that DSMAC had the largest improvement of 77.4% in the system throughput and 22.9% in the contention delay compared with the traditional distributed queuing MAC in 5G cellular IoT networks.

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