An Efficient Software Defined Data Transmission Scheme based on Mobile Edge Computing for the Massive IoT Environment

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Abstract

This paper presents a novel and efficient data transmission scheme based on mobile edge computing for the massive IoT environments which should support various type of services and devices. Based on an accurate and precise synchronization process, it maximizes data transmission throughput, and consistently maintains a flow's latency. To this end, the proposed efficient software defined data transmission scheme (ESD-DTS) configures and utilizes synchronization zones in accordance with the 4 usage cases, which are end node-to-end node (EN-EN), end node-to-cloud network (EN-CN), end node-to-Internet node (EN-IN), and edge node-to-core node (EdN-CN); and it transmit the data by the required service attributes, which are divided into 3 groups (low-end group, medium-end group, and high-end group). In addition, the ESD-DTS provides a specific data transmission method, which is operated by a buffer threshold value, for the low-end group, and it effectively accommodates massive IT devices. By doing this, the proposed scheme not only supports a high, medium, and low quality of service, but also is complied with various 5G usage scenarios. The essential difference between the previous and the proposed scheme is that the existing schemes are used to handle each packet only to provide high quality and bandwidth, whereas the proposed scheme introduces synchronization zones for various type of services to manage the efficiency of each service flow. Performance evaluations show that the proposed scheme outperforms the previous schemes in terms of throughput, control message overhead,

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and latency. Therefore, the proposed ESD-DTS is very suitable for upcoming 5G networks in a variety of massive IoT environments with supporting mobile edge computing (MEC).

Keywords: Mobile Edge Computing, Software Defined Network, Network Function Virtualization, Massive IoT, Synchronization

1. Introduction

During the past few years, mobile transmission and networking technologies, including wireless transmission and networking technologies (e.g. IEEE 802.11 and IEEE 802.15 family of wireless networking standard), have dramatically improved. In terms of performance, mobile technologies are no longer inferior to the various wired technologies. In addition, the 5G mobile technologies will accelerate these phenomena, and will also lead to the upcoming massive IoT era [1-2]. We are confronted with the 4th industrial revolution, which is based on technological innovation, and it has attracted public attention worldwide. The 4th industrial revolution is caused by various ICT evolutions, including mobile technologies, and it will certainly influence and transfigure most business fields. That is, it will provide great opportunities to all business stakeholders, especially in emerging markets.

Generally, the importance of artificial intelligence (AI) and robotic technology will increase in the 4th industrial revolution era, because all the connected things should be manipulated their operations automatically and intellectually. In this era, the most significant content will be algorithms and data, because all things will be operated by the results, which are processed by the algorithms and data, and these phenomena have already occurred in various business fields in the world. Therefore, how to gather data and how to utilize data by their own algorithms will be a critical technology. In addition, ICT and computational intelligence technique including the 5G technologies will be a most important foundation infrastructure, because we need a new methodology to aggregate data, and to process data [3-5]. Moreover, it will increase the necessity of convergence of various technologies, such as the Software Defined Network (SDN) and Network Function Virtualization (NFV), Mobile Edge Computing (MEC), Self-Adaptive Computing, machine learning, and efficient embedded software [6-7]. This will also provide new and big business opportunities for emerging markets, because these technologies, which can be utilized in company with the infrastructures, are usually based on various open source libraries; and a small-medium size company or start-up company can easily join the markets.

MEC can provide cloud computing capability and advanced ICT service environment to their network participants in the mobile network edges. It is particularly possible to support ultra-reliable low latency, ultra-high bandwidth, and the accessing of real-time network information. Besides, the MEC technology can be used for various services, it is highlighted as a key technique in the 5G mobile technology suite. There are 7 mobile edge computing service scenarios, these being 1) Intelligent Video Acceleration, 2) Video Stream Analysis, 3) Augmented Reality, 4) Intensive Computation Support, 5) Enterprise Deployment, 6) Connected Vehicles, and 7) IoT Gateway. Although there have been many researches and developments to satisfy the service scenarios, most researches and developments to date have only focused on a few service scenarios. This is because some service scenarios should be satisfied a high-end service goal, some service scenarios have to gratify a medium-end service goal, and some service scenarios have to meet a low-end service requirement [8-11]. Nevertheless, we need a common method that can be suitable for all the service scenario goals, since networking complexity should steadily decrease.

Like MEC, SDN/NFV technologies are one of the key components in 5G mobile networks. In IMT-Advanced networks researches into SDN/NFV technology have to date mainly focused on their core network components, and the applicable scope has usually been limited to the core networks. The applicable scope of SDN/NFV should be extended to their access or subscriber networks in the next generation networks (5G), since we had to reduce the core network component loads, and distribute computing loads toward the network edge. However, the researches of SDN/NFV for access networks are still insufficient, and there are many remaining things yet to do.

In distributed computing, such as MEC, the most important key capability is how to reduce transmission overheads to share parameters between distributed computing resources. In addition, the upcoming massive IoT environment, which should support various type of services and devices, should be considered when the key capability is implemented. In these cases, close cooperation between system H/W and their S/W will be needed to provide an architecture with scalability to support this environment.

To this end, we propose an efficient software defined data transmission scheme (ESD-DTS) based on mobile edge computing. The proposed ESD-DTS is a kind of data transmission scheme based on each node’s synchronization, which uses SDN/NFV technology to accommodate various types of service in the mobile network edge. In ESD-DTS, the participating devices are divided into different 3 groups, of low-end group, medium-end group, and high-end group, depending on the required service aspects. Each group uses a diverse synchronization period in accordance with their service aspects, and a service node in the mobile network edge adjusts their own buffer threshold values according to the pre-defined synchronization time. In addition, a virtualized service node in the edge transmits the buffered data to their own destination. In ESD-DTS, the data transmission methods in core and distributed networks utilize a safe data transmission method [12-13], which is also operated based on synchronization. By doing this, ESD-DTS can support various service types and devices that are required for 5G mobile services, and it can minimize the control message overheads, and data transmission delay. Moreover, ESD-DTS can constantly maintain latency that is suitable for the specific service type.

The rest of this paper is structured as follows. Section 2 discusses related works, which are related to the 5G key technologies based on the usage scenarios. Section 3 describes our proposed scheme in detail, and Section 4 evaluates the performance of the proposed ESD-DTS scheme. Finally, Section 5 offers concluding remarks.

2. Related Work

As is well known, there are important key capabilities in 5G mobile technology. In this generation, there are usage scenarios that enable IMT-2020 (5G) to outperform IMT-Advanced (4G). For example, **Fig. 1** shows that it is classified into enhanced mobile broadband (eMBB), ultra-reliable & low latency communications (uMTC), and massive machine type communications (mMTC).

eMBB will provide new user experience through ultra-high definition (UHD) and hologram imagery, virtual reality contents, etc. There are 2 key technologies. One is increasing network capacity technique, and the other is providing minimum throughput technique for each user. These will be achieved using various techniques such as Filter Band

Multi-Carrier modulation (FBMC), Non-Orthogonal Multiple Access (NOMA), Sparse Code Multiple Access (SCMA), Low Density Spreading (LDS), Sliding Window Superposition Coding (SWSC), Cooperative Multi-Point (CoMP), and Distribute Input Distribute Output (DIDO).

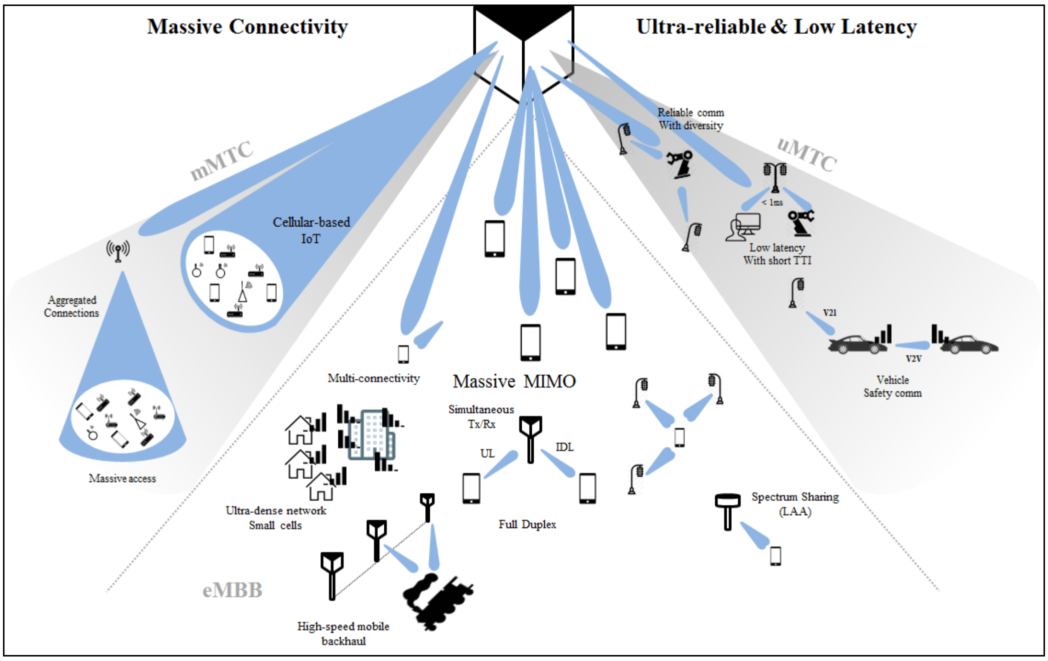


Fig. 1. Usage Scenarios in IMT-2020

uMTC is a kind of particular usage instance, and requires very strict latency and reliability to utilize it in various business fields, such as factory automation, remote surgery, and the autonomous vehicle. In uMTC usage cases, mobile networks have to decrease their own Transmission Time Interval (TTI) and Round Trip Time (RTT), because the networks should provide low-latency and ultra-reliable communications. Device-to-Device (D2D) communication technique and edge computing will be used in this case.

mMTC is a whole new usage scenario in IMT-2020, which wasn't ever considered in previous IMT evolutions. According to rapidly increasing IoT deployment, this usage can be the most important usage in IMT-2020 usage scenarios. IoT devices have different traffic attributes than legacy IMT devices. In other words, the required delay sensitivity is relatively low, the transmission data volume is also smaller than that of an existing participant's device, and a huge number of devices will be joined to the networks[14-18].

Meanwhile, the key capabilities in 5G network features are software-based virtualization, distributed network architecture, and access convergence. 5G networks should accommodate heterogeneous cells and smooth handover between various mobile and wireless access technologies. In addition, the networks have to determine a mobile & wireless access technology based on device, subscriber, and network status to provide best quality, and it should support service continuity and mobility by one identifier, whatever the device this is connected to a network.

Software-based virtualization is needed to provide network scalability and reduce expenses, since the legacy network items of equipment are tightly coupled to each other. By doing this, tightly coupled current network items of equipment can be efficiently divided into data and control planes, and can utilize various network components. The two separated planes can be interworked through the openflow technologies, and Fig. 2 shows that this is possible through the SDN/NFV.

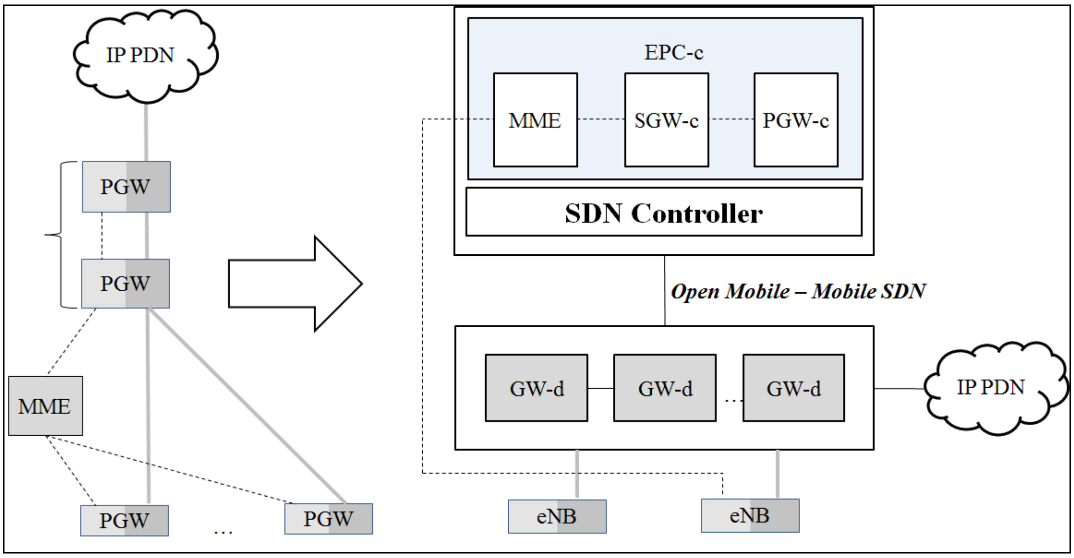


Fig. 2. Open Network Control based on a SDN

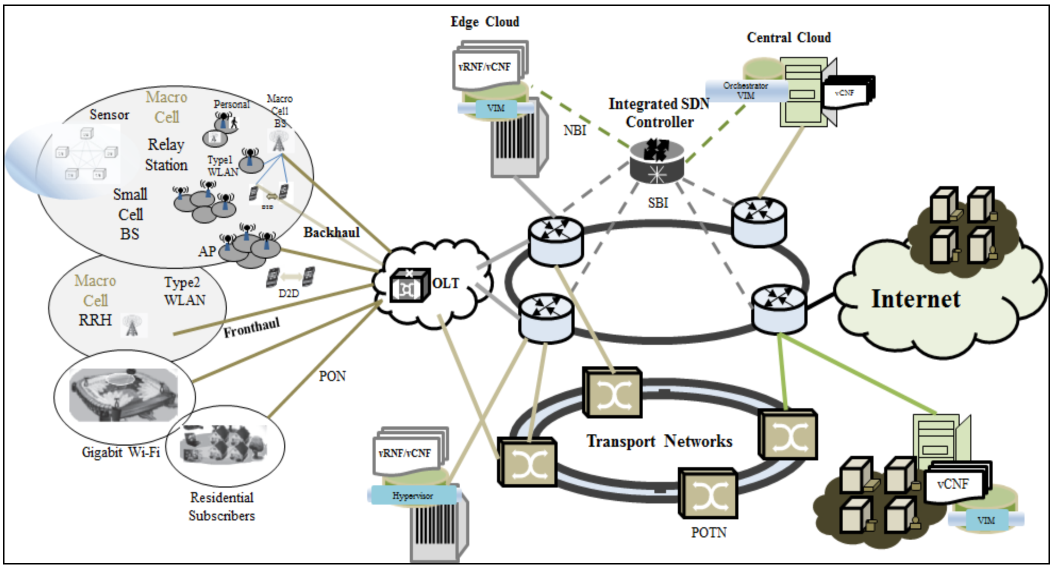


Fig. 3. The Distributed Network Architecture in IMT-2020

As is well known, current mobile networks have a centralized architecture, which consists of serving gateway, packet gateway, and Mobile Management Entity(MME). In this architecture, a gateway can be an unavoidable bottleneck point when large data will be transmitted, and this phenomenon will accelerate in 5G networks, because the networks should handle ultra-high volume data traffic. Moreover, the uMTC goal can’t be achieved in this network structure, since various application servers are connected to a central gateway.

Therefore, **Fig. 3** shows that a distributed network architecture is one of the most influential alternatives to solve the problems of the current centralized network structure. However, there are some mandatory requirements to be applied to the distributed architecture. This architecture must provide seamless handover, and a traffic distribution mechanism between regional gateways; and signaling message overhead has also to be reduced[19-21].

To satisfy the 5G network usage scenarios, the user-centric network, which can provide the best connectivity quality by concurrently utilizing several mobile and wireless networks, must be implemented. The user-centric network should support an integrated access control system, which can efficiently provide the best suitable connection method based on the status of various mobile and wireless resources. By doing this, all users and devices can concurrently utilize 2 or as many more networks as possible, and their service continuity can be assured.

3. Efficient Software Defined Data Transmission Scheme (ESD-DTS)

Generally, large-scale data traffic supporting 5G usage scenarios can't be accommodated by current mobile network structures, which consist of multiple layers and centralized packet gateways. To this end, 5G networks should be able not only to utilize a distributed network architecture, but also to minimize a signaling message for various IoT devices. To achieve these purposes, we propose an efficient software defined data transmission scheme (ESD-DTS), which can operate in a MEC-based distributed network architecture, and the proposed scheme can also support various type of services and devices for the massive IoT environment. In addition, the proposed ESD-DTS is very much more efficient than various legacy schemes, because the proposed scheme is based on very accurate and precise synchronization to expedite data transmissions. Although all devices in the ESD-DTS use this scheme based on a synchronization method to transmit data, the functional interface reference model is the same as the common 5G network model. The only difference is that the ESD-DTS uses accurate and precise synchronization within synchronization zones.

Fig. 4 shows that here are 4 synchronization zones in the ESD-DTM. Although the 4 synchronization zones are expressed as immovable areas, the scope of each zone can be dynamically adjusted according to the type of service or device, especially the location of the MEC cloud and SDN controller. This is because the proposed ESD-DTS aims at mobile edge computing, and a SDN controller manages synchronization and resource reservation.

There are 4 usage scenarios in the ESD-DTS, and these are as follow:

- Case 1 - Data Transmission Scenario between End Node and End Node (EN-EN): This is the case for device-to-device (D2D) communications in the 5G mobile usage scenario. It also includes heterogeneous network communications between 5G and Wi-Fi. This case is usually involved in synchronization zone 1, and considers the massive IT environment.
- Case 2 - Data Transmission Scenario between End Node and Cloud Networks (EN-CN): This is the case for using a MEC cloud and central cloud in 5G networks. Although it only depends on the location of the MEC cloud and central cloud, it usually operates in synchronization zones 1, 2, and 3, and it is also considered to the massive IT environment.
- Case 3 - Data Transmission Scenario between End Node and Internet Node (EN-IN): This is the case for handling outside data, such as to transmit to the Internet. In this case, ESD-DTS is commonly used for all synchronization zones, and the inside SDN controller should negotiate the synchronization process in correspondence with the outside SDN controller. In addition, the data transmission method in synchronization zone 4 utilizes the Safe Data Transmission Architecture(S-DTA) [13].

- Case 4 - Data Transmission Scenario between Edge Node and Core Node (EdN-CN): This case supports transmission of data between the edge cloud and central cloud. In most cases, seamless interworking functionality is one of the key capabilities for successful distributed computing, because the clouds should efficiently share information and resources between them. Therefore, this case is provided to manage these interworking functions. It is usually used in synchronization zones 2 and 3.

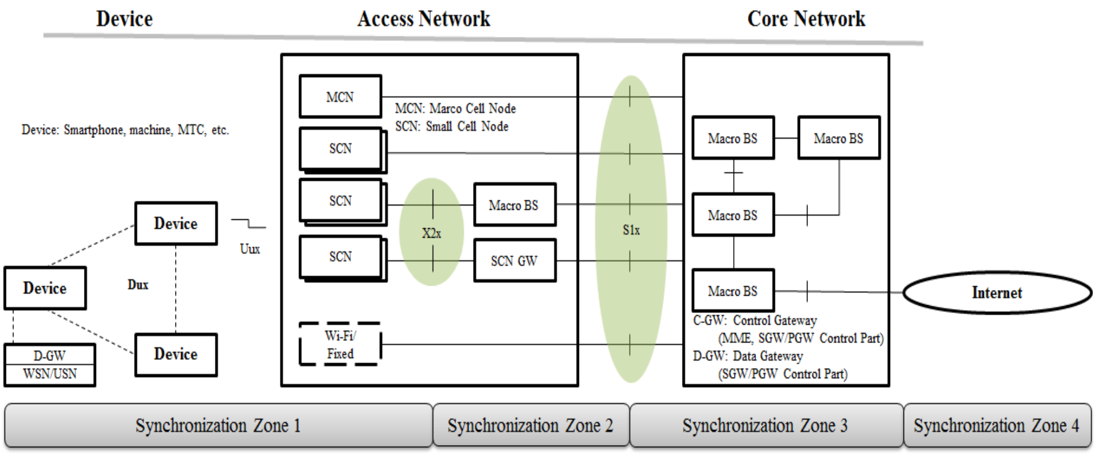


Fig. 4. Functional Interface Reference Model with Synchronization zones in ESD-DTS

In this ESD-DTS, the synchronization process is one of the key processes, because all devices transmit their data at a pre-defined time. When the next node receives the transmitted data within a pre-defined time, the next node immediately transmits the received data to their destination without any additional processing. By doing this, ESD-DTS can reduce transmission delay, and maintain constant latency. There are parameters that can affect this configuration setting. The details of this synchronization configuration process are follows:

- $e_1, e_2, \cdots, e_n$: This means electronic delay, and is the time to go through the circuit in the device. In most cases, this value almost converges to 0.
- $p_1, p_2, \cdots, p_n$: This means processing delay, and is the time to handle the received data in a receiving node. As is well-known, this delay is a main attribute to determine the entire delay, because the end-to-end delay value is the sum of Δp values.
- $s_1, s_2, \cdots, s_n$: This means serialization delay, and is the time to convert into a bit stream between transmission media. This value also converges to 0, the same as electronic delay.
- $t_1, t_2, \cdots, t_n$: This means transmission delay, and it is equal to light speed. Therefore, this value converges to 0, the same as electronic delay and serialization delay.

Arithmetically, the source-to-destination delay within n hops can be expressed as follows.

$$StD\_D_{all} = \sum_{n=1}^{n} (e_n + p_n + s_n + t_n) \tag{1}$$

Where, StD_D_{all} denotes a source-to-destination delay. In Eq. (1), StD_D_{all} is determined by p_n the value, because the other values (e_n, s_n, and t_n) are constant numbers. In other words, Eq.

(1) means that we can provide a constant delay to each flow, in the case where the $\sum_{n=1}^{N} p_n$ value can be steadily controlled during transmission time. Based on the Eq. 1, the StD_D_{hop} value at hop *i* can be expressed as follows:

$$StD\_D_{hop} = (e_i + p_i + s_i + p_i) - (e_{i-1} + p_{i-1} + s_{i-1} + p_{i-1}) \approx p_i - p_{i-1} = StD_{i-hop} \quad (2)$$

Where, StD_D_{hop} denotes a source-to-destination delay at arbitrary hop *i*, and StD_D_{i-hop} denotes an approximate source-to-destination delay at arbitrary hop *i*.

$$StD\_D_{all} = \sum_{n=1}^{n} (e_n + p_n + s_n + t_n) \approx \sum_{n=1}^{i} StD_{i-hop} = StD\_D_{approx-all} \quad (3)$$

Where, $StD\_D_{approx-all}$ denotes an approximate source-to-destination delay. To calculate the p_i and p_n value, ESD-DTS sends a synchronization calculation message (SCM) to a destination that is located within a synchronization zone, and ESD-DTS repeats these procedures several times. By doing this, ESD-DTS can get an average round trip time, and this value will be used for a synchronization initiation message (SIM). Based on this, the SCM_{all} can be expressed as follows:

$$SCM_{all} = \frac{\sum_{1}^{k_{try}} StD\_D_{approx-all}}{k_{try}} \quad (4)$$

$$SCM_{i-hop} = \frac{\sum_{1}^{k_{try}} StD\_D_{i-hop}}{k_{try}} \quad (5)$$

Where, SCM_{all} denotes a source-to-destination delay for the synchronization negotiation process within a synchronization zone, SCM_{i-hop} denotes an approximate source-to-destination delay at arbitrary hop i for the synchronization negotiation process, and k_{try} denotes the number of repetitions. The synchronization negotiation process in ESD-DTS uses a SIM that is based on the SCM_{all} and SCM_{i-hop}, and the SIM_{set} can be set as follows:

$$SIM_{set} = SCM_{all} - \sum_{n=1}^{all-i} SCM_{i-hop} + ET_{i-hop} \quad (6)$$

Where, ET_{i-hop} denotes an error tolerance at hop *i*, $e_{i-hop} + s_{i-hop} + t_{i-hop} \leq ET_{hop} \leq p_{i-hop}$.

As previously mentioned, the ESD-DTM carries out the synchronization processes by using this SIM, and these procedures are handled by the SDN controller. The detail state diagram and step are similar to the Information Exchange Architecture(IEA), Safe Data Transmission Architecture (S-DTA), and Efficient Peer-to-peer context awareness Data Forwarding Scheme(EP-DFS), which are described in [12, 13, 22], respectively.

Basically, all devices in the ESD-DTS are divided into 3 groups, the low-end group (LEG), medium-end group (MEG), and high-end group (HEG), as previously mentioned in Section 1. **Table 1** shows each group's features in detail.

Table 1. Device Groups for Synchronization in ESD-DTS

Group	Description
Low-End Group (LEG)	• Required Bandwidth: Mbps class or higher • Features: Requires a high bandwidth • Delay Sensitivity: Depends on required service type • Usage Case: CCTV, HD or UHD Surveillance Camera System, etc.
Medium-End Group (MEG)	• Required Bandwidth: Kbps class • Features: Requires a medium bandwidth • Delay Sensitivity: Depends on required service type • Usage Case: Telematics and Home Automation devices, etc.
High-End Group (HEG)	• Required Bandwidth: bps class • Features: Requires a low bandwidth • Delay Sensitivity: Depends on required service type • Usage Case: Various sensor node or device, etc.

Since the ESD-DTS is an evolved method from Refs. [12, 13, 22], it can easily handle the HEG and MEG to utilize the method that is described in the previous paragraphs. However, this method can't be applied to the LEG, because the previous schemes haven't been considered in terms of ultra-low bandwidth services. To solve this problem, the ESD-DTS uses the following method.

Although it depends on the amount of data in the LEG's device buffer as well as SIM_{set} value, the ESD-DTS takes different operations, as follows:

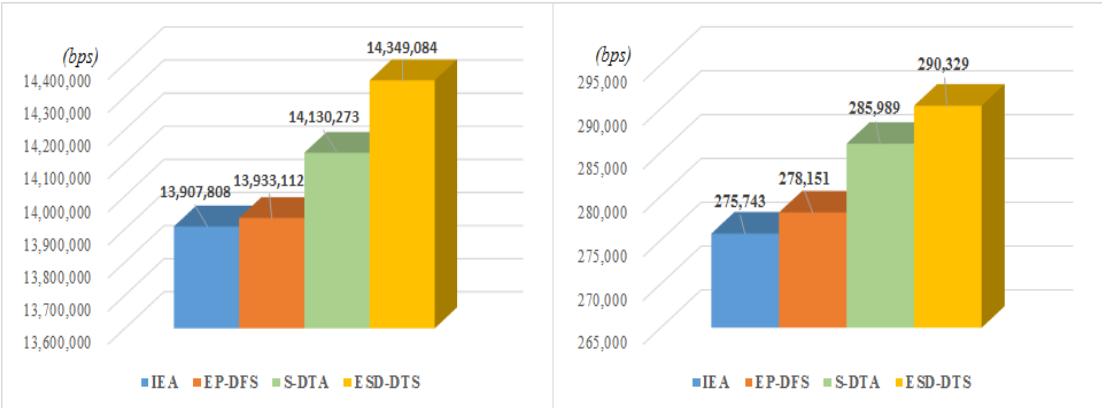
- Case 1: This is the case that the LEG's node has accumulated data of which the size is less than the buffer threshold, and does not receive SIM_{set} message from any handling node.
- Case 2: This is the case that the LEG's node has accumulated data of which the size is less than the buffer threshold, and does receive SIM_{set} message from any handling node.
- Case 3: This is the case that the LEG's node has accumulated data of which the size is equal to or greater than the buffer threshold, and does not receive SIM_{set} message from any handling node.
- Case 4: This is the case that the LEG's node has accumulated data of which the size is equal to or greater than the buffer threshold, and does receive SIM_{set} message after data transmission.

In most cases, the LEG's node has an active time to reduce their energy consumption, as is well known. Therefore, the ESD-DTS starts the synchronization negotiation when the LEG's node is awake, and the negotiated SIM_{set} value is set within their activation time. That is, the LEG's node SIM_{set} value range is $0 < SIM_{set} < T_{avg\_active\_time_{i-node}}$, where $T_{avg\_active\_time_{i-node}}$

denotes an average activation time of node i, and the average time calculation method is well described in Ref. [7, 23, 24].

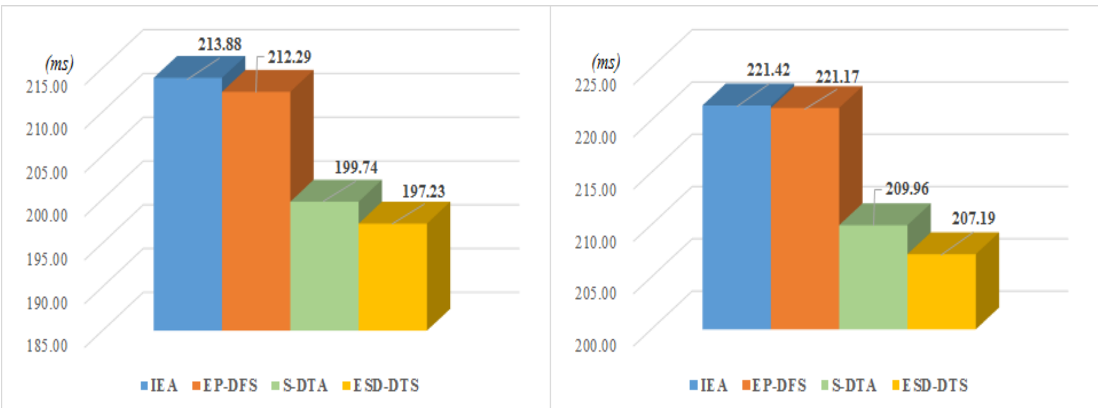
4. Experimental Classification Results and Analysis

We carried out computer simulations to verify the performance of the proposed ESD-DTS. The throughput comparisons with IEA, EP-DFS, and S-DTA were performed in terms of HEG and MEG, where the latency comparisons are the same as the throughput comparisons. This is because the proposed ESD-DTS is evolved from these schemes, and these schemes are suitable for HEG and MEG. In the simulation topology, there are 50 nodes that belong to HEG in the source side, and 5 nodes in the destination side. The 1 MEC server is included in this destination side. In addition, we prepared the topology for MEG simulations, the same as for HEG simulations. The maximum target bandwidth was 15,728,640 bps (15 Mbps) for the HEG, and 327,680 bps (320 Kbps) for the MEG. Finally, the transmission data type used a streaming traffic type for each group, because this traffic type has high delay sensitivity.



(a) *Throughput Comparison for HEG with the others* (b) *Throughput Comparison for MEG with the others*

Fig. 1. Throughput Comparisons with the others:
(a) Throughput Comparison for HEG with others; (b) Throughput Comparison for MEG with the others



(a) *Latency Comparison for HEG with the others* (b) *Latency Comparison for MEG with the others*

Fig. 2. Latency Comparisons with the others:
(a) Latency Comparison for HEG with the others; (b) Latency Comparison for MEG with the others

Fig. 5 shows average throughput comparisons with IEA, EP-DFS, and S-DTA, while **Fig. 6** shows average latency comparisons with the others. **Fig. 5 and 6** show that the ESD-DFS outperformed the others in terms of throughput and latency. This means that ESD-DTS is more efficient than the other schemes, because it is not only uses an improved synchronization method, but also effectively utilizes a network resource based on edge computing. There are common circumstances in the HEG and MEG. This is because the ESD-DTS can configure to achieve a more accurate and precise synchronization time than the others.

In our performance simulation model for the LEG, we randomly distributed 1,000 LEG nodes in the source side. **Table 2** shows the reference parameters. In this case, we configure the total packet length to be 10 bytes, data packet size of 30 ~ 300 bytes, default buffer size of all LEG nodes as 2,048 KB, and threshold value of 1.

Table 2. Reference Parameters and Variables

Parameter and Variable	Value
Contention Slots	384
Duty Cycle	25%
Frame Length	1 ms
Probability Variable	$0 \le P(\varrho) \le 1$, $0 \le P(\tau) \le 1$
Data Distribution	Poisson, Constant bit rate (CBR)
Threshold Variable	$0 < k_2 \le 1$

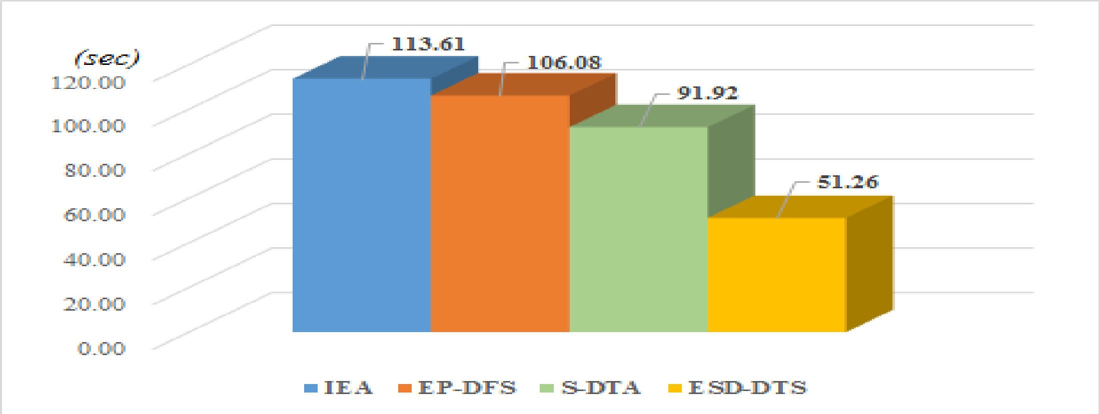


Fig. 3. Transmission Delay Comparison with the others

Fig. 7 shows the average transmission delay comparisons with the others. The figure, shows that the transmission delay performance of ESD-DTS dramatically outperforms the other schemes. This means that ESD-DTS is well designed for the massive IoT environment. It also means that the synchronization method for the LEG node is very suitable for the activation time of each node. Therefore, the proposed ESD-DTS can efficiently accommodate the massive IoT environment.

5. Conclusion

In this paper, we present ESD-DTS that provides flow efficiency for each service by using a synchronization method based on the specific zone. This scheme is a novel, flexible, and scalable scheme that is very suitable for the upcoming 5G mobile networks. All service flow experiences adequate throughput, low latency, and minimized control message overhead in ESD-DTS, because data will be accurately transmitted to their devices within the estimated time. Moreover, ESD-DTS gets rid of the unnecessary processing time based on the specific synchronization method, and it supports various type of services by using a group that reflects their service requirements. Finally, the ESD-DTS effectively supports mobile edge computing to share computing resources for the massive IoT environment. The excellence of ESD-DTS is already verified by its outperformance of the other schemes in various performance evaluations. Therefore, the proposed ESD-DTS can be utilized for diverse applications when it comes to 5G mobile networks, and it is certainly useful scheme for emerging markets. Finally, in further research, we intend to address a more effective synchronization method and security issues.

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