# Transmission of Augmented Reality Contents Based on BLE 5.0 Mesh Network

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**Abstract.** In recent years, Augmented Reality (AR) applications have appeared on smart devices (smartphones, smart glasses, etc.) that have expanded the visual perception of users. With the appearance of new technologies, a huge number of new services are created and the quality of service provision for them also plays a really important role. Thus, the task of Quality of Experience (QoE) introduces interest to suppliers, service developers and users. This article discusses the issues of QoE in the implementation of AR services in big cities with a high density of users but not all users have the Internet access. To solve this problem, we propose to use Bluetooth 5.0 technology (BLE 5.0) to access the network. The interaction between the client and the server can be carried out by using D2D communication on BLE 5.0 through smartphones of other users, which are described by the queuing system model. The proposed model of providing augmented reality services was simulated. The simulation results show delays in the delivery of data, which depends on the number of BLE 5.0 nodes through which data is exchanged between the AR client and AR server, and also on the load factor.

**Keywords:** BLE 5.0 · Mesh network · Augmented reality
Delay · Quality of experience · Service system · Data transmission
Device-to-Device (D2D) communication

## 1 Introduction

Nowadays, the concepts of the Internet of Things and the Augmented Reality [1–3] are used very popularly, which represent the integration of a huge volume of data, information with real objects from the world around us. AR applications typically add information to an object that will be at first recognized and

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then sent to the server. Depending on the application, the information coming in and out of the server may be different. For example, there can be a full-fledged video stream in one direction, and only text data in the reverse direction. Currently, this is not a problem due to the diverse range of modern devices' features. Smartphones, tablets and other smart devices are ideal elements for the implementation of AR services. Today smart devices not only support high-speed connections, but also have a powerful processor, camera, a graphical interface and an acceptable price that is accessible to any user.

Many AR applications can be implemented on these smart devices because they do not require complex processing of information. Typically, these AR applications are about the recognition of object and the display of information about it. However, there are other applications that require significant bandwidth, complex processing power, and a stable wireless communication channel. In big cities, with a high density of users and their constantly high activity to realize the representation of various AR services with a proper QoE can be quite problematic. One of the solutions to this problem is the use of D2D communications [4,5]. The basis for D2D communication can be Bluetooth 5.0 standard, which has a number of winning features [6]. Firstly, it provides a throughput of 2 Mbit/s to users, secondly, it operates at a distance of 70–100 m, and thirdly, it has the property of self-organization.

This article considers the possibility of using Bluetooth BLE 5.0 to provide AR services, in condition that a wireless channel is provided for the exchange of data between end-to-end devices so that the remote device can receive a response from the AR Server. In this case, the characteristics of the BLE mesh network and the queuing system model of the AR application in this network are considered. Simulation modeling in the AnyLogic program [7] was carried out. The results show delays in the delivery of data, which depends on the number of BLE 5.0 nodes and through these nodes data is exchanged between the AR client and the AR server, and also on the load factor.

## 2 Overview of Bluetooth 5.0 and BLE Mesh

Today, Bluetooth technology is one of the most popular wireless technologies in personal networks. Until now, different versions of the Bluetooth protocol are often used in many areas of life on various devices. Each new version of the protocol (1.2, 2.0, 2.1, 3.0, 4.0, 4.1, 4.2 and 5.0) introduces significant improvements in its operation. An important achievement is the maintenance of a low power mode, starting with version 4.0 (Bluetooth Low Energy - BLE). Recently a new version 5.0 is released, which improves many features such as speed, range, energy efficiency and the way in which the network is organized [9]. The following new features of Bluetooth 5.0 technology should be highlighted:

- 8x increased broadcast capacity.
- 2x data rate.
- 4x long range.
- Improving noise immunity.
- Improving energy efficiency.
- LE Advertising Extensions.

At the physical layer, Bluetooth 5.0 uses a variety of modulation schemes, encoding schemes, and data transfer rates. The physical layer data is presented in Table 1.

**Table 1.** The physical layer of Bluetooth 5.0

| PHY | Modulation scheme | Encoding scheme | | Data rate |
|---|---|---|---|---|
| | | Access header | Payload | |
| LE 1M | 1 Msym/s | Uncoded | Uncoded | 1 Mbps |
| LE 2M | 2 Msym/s | Uncoded | Uncoded | 2 Mbps |
| LE Coded | 1 Msym/s | S = 8 | S = 8 | 125 Kbps |
| | | | S = 2 | 500 Kbps |

Presently, the maximum data rate is doubled to 2 Mbit/s. Along with the achievements presented in Bluetooth 4.2, the bandwidth is increased 5 times compared to the original level of Bluetooth 4.0. The new version of Bluetooth 5.0 also supports BLE mesh, which creates more communication possibilities between several devices. BLE mesh was released independently and after the announcement of Bluetooth 5.0. This means that applications can use BLE mesh together with Bluetooth 4.x or 5.

In July 2017, the Bluetooth SIG (The Bluetooth Special Interest Group) published the first version of the mesh profile specification for Bluetooth [10]. It defines a mesh network based on a flooding-based solution that uses advertising channels to send messages so that the other nodes can receive and relay them. Any device on the network can send messages at any time if there is sufficient density of devices for listening and relaying the message. In order to limit the number of relaying messages, there are several methods presented in the specification [10]. The main methods are:

- Time To Live (TTL): Each message includes a TTL value that limits the number of times a message can be relayed.
- Network message cache (NMC): NMC is designed to prevent devices from relaying previously received messages by adding all messages to a cached list.
- Relay is optional: all nodes do not need to implement the relay function.

In the specification [10], the packet size is 33 bytes. The packet format is shown in Fig. 1. Each packet includes 12 or 16 payload bytes. In the case payloads exceed 12 or 16 bytes, there is a process of segmentation and reassembly. Therefore, in order to send a message in size of 120 bytes, it is required to segment the message into 10 packets.

Combining the capabilities of Bluetooth 5.0 and the mesh network has become a new solution for providing various services. In the next section, we consider using Bluetooth 5.0 Mesh for AR applications.

| | 1 | | 1 | 3 | 2 | 2 | 12 or 16 | 4 or 8 |
|---|---|---|---|---|---|---|---|---|
| IVI | Network ID | CTL | TTL | Sequence Number | Source Address | Dest Address | Packet Payload | NWK MIC |

**Fig. 1.** Packet format of BLE mesh network

## 3 Implementation Model

With Bluetooth 5.0 support, mobile phones can exchange messages between a few devices. Taking into the discussed above features of Bluetooth 5.0, we propose a following model for providing augmented reality services, which is depicted in Fig. 2.

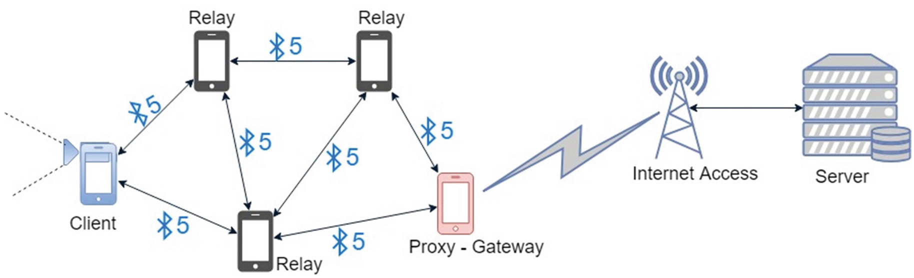


**Fig. 2.** Bluetooth 5.0 mesh network model for AR application

The Fig. 2 shows the following components:

- AR-Client: A node that uses its camera to recognize objects and sends requests to the server to find information about this object. In addition, with using the GPS sensor and the orientation sensor, the AR-Client can send requests to find information about the place where it is located. After receiving responses from the servers, information will be displayed on the device. Messages are transmitted by AR-Client over advertising channels.
- Relay: Nodes that receive the messages and then relay them over the advertising channels, if these messages did not arrive earlier. On these nodes, NMC and TTL method are used.
- Proxy-Gateway: A node that has access to the Internet. It provides data exchange between a AR-Client and a remote server.
- Internet Access: It provides Internet access service.
- Server: It receive requests from AR-clients and after request processing the answers will be sent back to AR-Client.

Thus, a waiting time between the client request time and the server response time is one of the main performances of service quality. Before sending a request, the subscriber terminal (smartphone) also spends time on recognizing the surrounding objects. Thus, this total time can affect user's quality of experience. Figure 2 shows that the waiting time depends on several components, specifically, subscriber terminals, communication network and cloud server. When implementing a particular service, the influence of each element of the service model is considered in more detail. The delay introduced by terminals depends on the characteristics of the devices and the functions of the AR application. The delay introduced by communication networks depends on the used technologies for data transmission, on the networks bandwidth and on the volume of transmitted data. In the BLE mesh network, there is a small bandwidth, as well as a small payload size. However, the new version of Bluetooth 5.0 announced an increase in payload size. And the delay introduced by the cloud server depends on its performance when data processing.

The Bluetooth mesh network allows to transmit small amounts of data, when sending a larger message segmentation and reassembly at the reception are required. In addition, in this network, packets are relayed through nodes to the source (gateway), therefore the network scale or the number of transit nodes will affect the delivery delay between the client and the server. Thus, the delay introduced by the network most of all affects the quality of transmission when implementing the service. We consider the delay, including the time required for delivering packets between the client and the gateway through a certain number of transit nodes, and the time required for delivering the message between the gateway and the server over the cellular network. We describe service process for AR-client by the a multiphase queuing system model. Each Relay node, gateway, and cloud server is a single-phase queuing system.

Assume that the packet flows arriving at each service phase can be described by the simplest flow model. The Bluetooth mesh network [6,10] uses a flooding-based routing method. The packet flows can be transmitted through many nodes to other nodes. Each Relay node can receive the same message. With a sufficiently large number of users, the incoming packet flow will have properties close to the simplest flow.

A queuing system model is shown in Fig. 3.

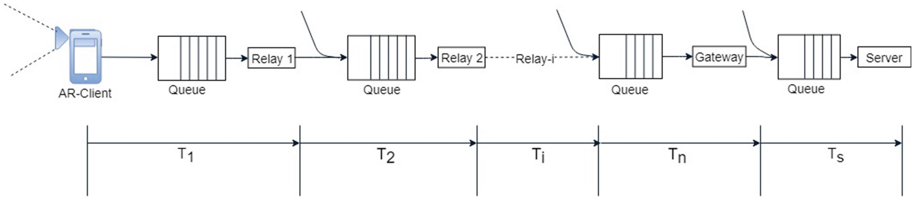


**Fig. 3.** Queuing system model of AR-Client

Assume that the AR client sends a message with a size of 120 bytes; consequently, this message is segmented into 10 packets. As follows from Fig. 3, data transmission process between the AR client and the server can be described in the following way:

- Each packet is sequentially transmitted to Relay-1 node with an average delivery time $T_1$.
- Then the Relay-1 node relays the packets to Relay-2 node. The average delivery time between the first and second nodes is $T_2$. To guarantee great reliability of delivery, the Relay-1 node can be configured to repeat retransmission of the same packet [10]. Generally, the Relay node repeats the packet retransmission 3 times with a minimum repetition delay, called the retransmission interval: $Interval_{retrans} = (Steps{+}1){\cdot}10{+}(0 \rightarrow 10\,\text{ms})$, where $Steps = 1, 2, 3$.
- Similarly, the following Relay-$i$ nodes have a packet delivery time $T_i$ and retransmission intervals $Interval_{retrans}$.
- After the gateway received all of 10 packets, it collects the segmented packets into one message. Then the received message is sent to the server.

In such a queuing system, great interest is represented by a model, which describes the principles of the functioning of its elements. Obviously, when investigating in various models, it is required to determine the delay time for the augmented reality data delivery, i.e. it is necessary to determine probability that the data delivery time will not exceed a definite value $T_0$. Currently, models are known for typical queuing systems [11], for example, when the service time at each node, or at each phase, is random and has an exponential probability distribution. When describing the queuing system model M/M/1 at each phase, the average packet transit time at the $i$-th phase is represented by the following expression:

$$T_i = \frac{1}{\mu_i - \lambda_i} \tag{1}$$

In the case when the incoming packet flows at each phase of the queuing system are independent and have the same properties (the simplest flow), the average delivery time is equal to sum of the mean delivery times of each phase of queuing system. Also, when delivering a large message, it is necessary to consider the delivery time of packets that are received after segmentation. Thus, the average delivery time between the AR-client and the server is represented as:

$$T = m \cdot \sum_{i=1}^{n} T_i + T_S = m \cdot \sum_{i=1}^{n} \frac{1}{\mu_i - \lambda_i} + \frac{1}{\mu_S - \lambda_S} \tag{2}$$

Where:

- $m$ is a number of packets after message segmentation
- $n$ is a number of passing phases of queuing system to the server
- $\mu_i$ and $\mu_S$ are service rate at each phase of the Relays and Server
- $\lambda_i$ and $\lambda_S$ are arrival rate at each phase of the Relays and Server.

Let's assume that the arrival rate of incoming packets at each Relay node is the same. As follows from formula (2), the data delivery time between the

AR-client and the server is represented as:

$$T = \frac{m \cdot n}{\mu_i - \lambda_i} + \frac{1}{\mu_S - \lambda_S} \tag{3}$$

## 4 Simulation Modeling

In this article, simulation modeling is carried out with using the AnyLogic package. The model is constructed similarly to that shown in Fig. 3. In the process of modeling, the number of transit nodes Relay is changed, i.e. the number of passing phases of queuing system from the client to the server is changed. The following parameters were chosen as the experimental conditions: time of each experiment, $t_{exp} = 100$ s; data transfer speeds of Bluetooth 5.0, DR = 1 Mbps and 2 Mbps; message size (payload size), L = 120 bytes and 240 bytes; mean arrival rate at each Relay node, $\lambda_i = 0.7$; mean service rate at each node for types PHY 2 Mbps and 1 Mbps, $\mu_i = 1.1$ and 0.97; mean arrival rate on the server, $\lambda_S = 2.08$; and mean service rate on the server, $\lambda_S = 1$.

When changing the number of transit nodes from the client to the server, values of such parameters as the delivery time of all segmented packets between the client and the gateway and the delivery time of messages between the gateway and the server were measured. By the sum of these times, we can estimate the data delivery time between the client and the server. Measurements of these parameters were carried out when delivering messages in size of 120 and 240 bytes.

When modeling the delivery of a message with a size of 120 bytes, the load factor was changed, accordingly, the arrival rate of incoming packets at each phase of queuing system was changed, and the delivery time between the client and the server was measured.

As the simulation results, graphs of dependencies of packet delivery delay on the number of transit nodes Relay, on the size of the transmitted message, and on the load factor were obtained. Theoretically, according to formula (3), similar dependences for these parameters were also obtained. When transferring a packet with size of 240 bytes, the theoretical and simulated results are compared in Figs. 4 and 5, respectively, depending on the number of Relay nodes and depending on the load factor. Comparisons of simulation results with two sizes of the packet 120 and 240 bytes are shown in Figs. 6 and 7, respectively, depending on the number of Relay nodes and depending on the load factor.

As follows from graphs, in this case, the delivery time increases linearly with changing the number of transit nodes Relay. The results of theoretical calculations confirm the results obtained in the course of simulation modeling. Figures 4 and 6 show that the delivery time of message of 240 bytes is 1.8 s when using LE 1M mode (PHY 1 Mbps), and 0.9 s when using LE 2M mode (PHY 2 Mbps), in case where there are 25 transit nodes between the AR client and the server. In the latest version of the BLE mesh model specification, payload size of 16 bytes was determined; because message delivery occurs with data segmentation, the message delivery time will be more required. Thus, it is obvious that the

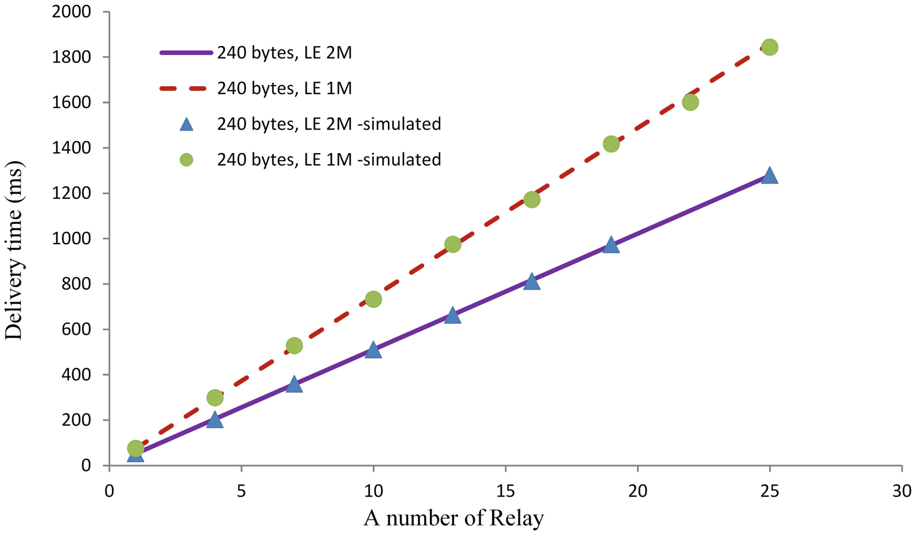


**Fig. 4.** Delivery time depends on number of Relay nodes

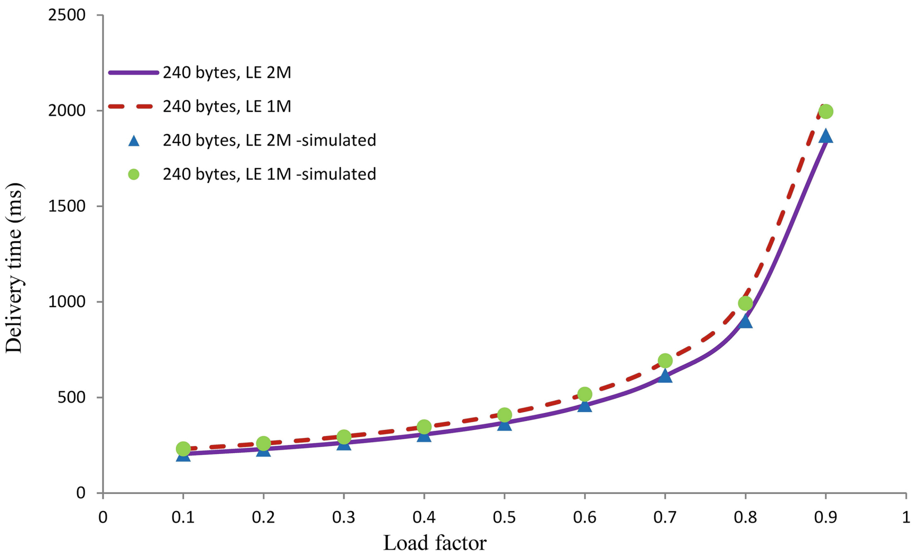


**Fig. 5.** Delivery time depends on the load factor

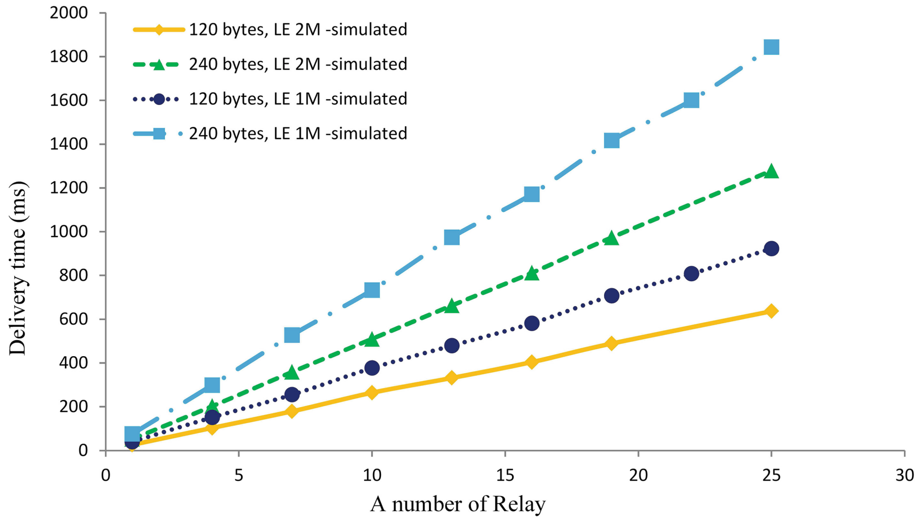


**Fig. 6.** Delivery time depends on number of Relay nodes (AnyLogic)

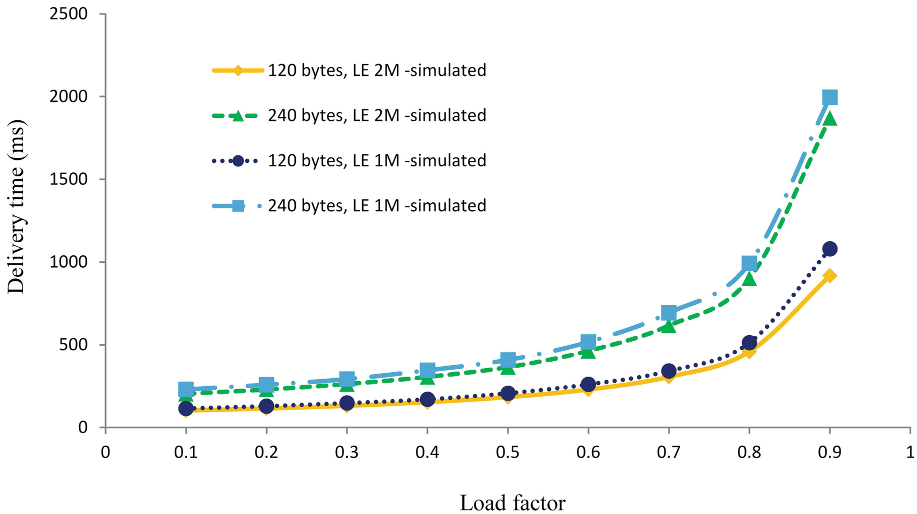


**Fig. 7.** Delivery time depends on the load factor (AnyLogic)

size of message affects the delivery time between the AR client and the cloud server. When comparing two messages with sizes of 120 and 240 bytes (Fig. 6), it is obvious that the delivery time of a message with size of 120 bytes is less than 2 times. Therefore, when implementing the augmented reality services, it is required to determine the amount of data to be delivered to AR clients.

The Figs. 5 and 7 show the effect of the load factor on the message delivery time between the AR client and the cloud server with a number of transit nodes equal to 10. The results in these figures show that the delivery time of message in size of 240 bytes was longer than 2 s with a load factor of 0.9, and the delivery time of message in size of 120 bytes was required more than 1 second. Thus, with a high user density, the data delivery time can reach up to several seconds. In this network, with a large number of transit nodes and a large load factor, the quality of service provision may not be provided in the proper way. Therefore, analyzing the results we can choose the appropriate delivery option for the implementation of a particular augmented reality application with considering the network scale, the number of transit nodes, and the amount of provided data.

## 5 Conclusion

In recent years, many new technologies have appeared which bring to the market a wide range of various services that can surprise the most demanding user. All sorts of information about the objects, from the world around us, are collected and stored. Today, every person has access to such information and there are a number of methods and technologies for displaying data to the users. One of methods is the augmented reality technology, which uses different ways of object recognition, data delivery of the object and the form of information presented to the user, which increases its mobility, convenience of searching and data perception.

The article considered the possibility of AR services based on the mesh network BLE 5.0 in big cities with a high density of users when not all the users have the Internet access. A service model as queuing system was proposed that describes the process of delivering a message between the AR client and the AR server. In this model, the AR data delivery over a mesh network BLE 5.0 was simulated in AnyLogic package. The simulation results showed a series of dependencies of the delivery time between the AR-client and the AR-server from various parameters.

Depending on the network scale, the delay in the delivery data between the AR client and the cloud server increases with the number of transit nodes Relay. It was also found that the size of message affects the packet delivery time over the network. With the increase of the load factor, the delivery time also increases. When considering the high density of users, i.e. at a great load factor, the delivery time can reach several seconds.

From these results, it can be concluded that the mesh network BLE 5.0 is capable of providing the required quality of information delivery for augmented reality services. Thus, when implementing an AR application in this network, it is necessary to consider the message size and the possible number of nodes in the network in order to minimize the delivery time between the client and the cloud server. In the near future, the specification of BLE mesh model is expected to be updated, which will make full use of the advantages of Bluetooth 5.0 for increasing the payload size.

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