Quality-of-Service in Machine-to-Machine Service Provisioning Process

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***Abstract*—This paper tackles the problem of Quality-of-Service (QoS) in heterogeneous Machine-to-Machine (M2M) systems. The concern for QoS guaranties has been widely expressed in the past for both wired and wireless networks. However, only recently when these two types of networks have converged into one, thus making one huge heterogeneous system called M2M, new concerns have emerged. In this paper we measured energy consumption for different communication technologies and proposed an energy consumption model for iOS devices that can be used in future QoS specifications. Finally, we defined a QoS metric that includes both energy and time consumption aspects of one simple M2M service.**

***Keywords*—Bluetooth 4.0, energy efficiency, QoS metric, heterogeneous system;**

I. INTRODUCTION

The notion of Quality-of-Service (QoS) has been introduced to capture the qualitatively and/or quantitatively defined performance contract between user applications and the service provider. It was firstly defined by the International Telecommunication Union (ITU) as the set of requirements on all the aspects of service aiming at the degree of satisfaction of a user of the service [1]. Since then, a lot of work has been done in the area of QoS in both wired and wireless networks. Special attention has been given to the QoS in wireless networks since they are more resource constrained than wired networks (e.g., in IEEE 802.11 networks [2], mobile ad hoc networks [3], ad hoc wireless networks [4], and mobile networks [5]). Recently, different communication networks converged into one large heterogeneous network that is used for communication in Machine-to-Machine (M2M) systems, opening new research challenges.

Different machines (e.g., sensors, meters) in an M2M system capture "events" (e.g., temperature, inventory level), which are transmitted through a network (e.g., wireless, wired or hybrid) to an application that translates them into meaningful information (e.g., items need to be restocked) [6]. From the QoS perspective, in the service provisioning process, networks of different characteristics can be used. According to that, the research challenge is how to provide end-to-end QoS guarantees despite the limitations of different means of communication. Namely, when providing services in M2M systems, service providers have to be very careful when agreeing on certain QoS parameters.

Although some initial efforts in the area of M2M standardization have been made, notably within the European Telecommunications Standards Institute (ETSI) [7] and the 3rd Generation Partnership Project (3GPP) [8], QoS in M2M has not yet been considered. However, the problem of QoS in M2M systems has been identified [9]. In 2011 Lien at al. proposed a solution to provide QoS guarantees to facilitate M2M applications with inviolable hard timing constraints [10] [11]. Their solution is based on an idea of a Massive Access Management (MAM) for QoS guarantees in M2M communication, but only for M2M systems proposed by the 3GPP where each M2M device attaches to the existing mobile cellular infrastructure. In that way, their solution is not applicable in every M2M system, since in the literature only few realizations of M2M communication leveraging different communication technologies have been proposed.

In this paper we measure time and energy consumption when uploading and downloading data using Bluetooth 4.0, Wi-Fi, and 3G communication technologies. Moreover, we propose an energy model that can be used for energy consumption calculations. In our previous work [12], we made a model for Bluetooth 3.0, and in this paper we extended it to a new generation of technology. Furthermore, we define a QoS metric that is based on time and energy consumption for one simple M2M service and show how the same service has different QoS when using different communication technologies. The rest of this paper is organized as follows. Section II presents related work, while Section III describes different communication technologies used in our measurements. Section IV presents results of the measurements and proposes an energy consumption model for iOS phones. In Section V we define a QoS metric in M2M provisioning system. Finally, Section VI gives concluding remarks.

II. RELATED WORK

QoS parameters are key factors for evaluating if technologies, services, and applications meet customer expectations for quality, availability, and reliability [13]. Each new product faces a challenge of delivering a QoS equal or better than existing products. Therefore, service providers have to find new ways of improving their services, even in heterogeneous environments. Quality-of-Service can be looked at from two major perspectives: network perspective and application/user perspective [14].

From the network perspective, QoS refers to the service quality that networks offer to applications or users. Network QoS parameters are latency or delay of packets, reliability of packet transmission, and throughput. From user perspective, QoS parameters are usually subjective, e.g. presentation quality of the video, sound quality of streaming audio, etc. Generally speaking, a QoS is defined as the performance level of a service offered by the network to the user [15]. A QoS has become a stringent requirement for real-time applications and enables more efficient sharing of network resources. It manages time-sensitive multimedia and voice application traffic to ensure it gets a higher priority, since greater delays cause serious deterioration in the provided service.

QoS parameters differ from application to application. For instance, in multimedia applications bandwidth and delay are most common parameters [14]. In military services, these parameters rely mostly on security and reliability aspects. In routing protocols, besides delay and packet delivery ratio, the routing overhead is also taken into account (i.e., the number of routing packets transmitted per data packet). However, the common metric includes only following parameters: delay, delay variance (jitter), packet loss ratio, and data rate.

M2M systems have their own QoS requirements [16]. Since there are a large number of M2M services, like mobile streaming, smart metering, regular monitoring, emergency alerting, or mobile payment, it is suggested that these services are described according to the high or low need for a real-time transmission, accuracy, and priority. For instance, service that includes emergency alerting has a high delay variety and high real-time requirements, while a regular metering service does not have such strict requirements.

QoS parameters are defined separately for different technologies. ETSI defines Quality-of-Service parameters in technical specification on Digital Cellular Telecommunications System (DCTS) and Universal Mobile Telecommunications System (UMTS) [17], speech and multimedia transmission [18]. ITU-T defines various standards for IP Networks and Services [19]. Manufacturers and service providers also define their own QoS specifications for routers, servers, etc.

In today's communication systems, power efficiency has become equally important as QoS, especially in M2M systems where devices are of lower energy capacities, including smartphones, and especially sensors. Various suggestions for improving communication network architecture in order to enhance energy efficiency have been proposed [20][21].

III. Different Communication Technologies

In its standards ETSI has proposed the functional architecture for M2M systems [22]. It consists of two different domains: network, and device and gateway domains. M2M devices connect to a network either directly or through gateways. In the latter scenarios, an M2M area network provides connectivity between M2M devices and M2M gateways. It can be based on one of the following Personal (PAN) or Local Area Network (LAN) technologies: Zigbee, Bluetooth, (Wireless) M-BUS, etc. In the rest of the section we will describe different communication technologies that are usually used in M2M systems.

A. Bluetooth 4.0

Bluetooth 4.0 standard [23] includes different protocol specifications: classic/enhanced (basic rate/enhanced data rate; BR/EDR) and Bluetooth low energy (BLE). BR mode supports over-the-air data rate of 1 Mbit/s, while EDR boosts a data rate up to 3 Mbit/s. The basic hopping pattern is a pseudo-random ordering in the industrial, scientific and medical (ISM) radio band. It was created as an ultra-low power communication mechanism with future M2M deployments in mind, enabling BLE devices to operate for months or even for years on a single coin-cell battery. BLE achieves data rates up to 1 Mbit/s, is suitable for short-range low-duty-cycle applications where low-power consumption is important, and similar to classic BT, also uses adaptive frequency hopping spread spectrum to access the shared channel. The BLE system uses forty frequency channels separated by 2 MHz, three of which are used as advertising channels and the rest as data channels, as opposed to 79 hops and 1 MHz channel width in classic BT.

BLE device can operate either in a role of a master or a slave. Unlike scatternet in BR/EDR, BLE network topology is a star. This is achieved because BLE device acting as a master can manage multiple simultaneous connections with slave devices, but slave can only be connected to a single master. A master BLE device scans three designated advertising channels in order to discover nearby slaves, and when it does, it can initiate a connection by sending the connection request to the targeted slave device. BLE devices in connected state are able to exchange data in the form of connection events in which they both wake up in synchrony to exchange frames, while the rest of time they are in a sleep mode.

B. Other communication technologies

Wi-Fi is a local area wireless technology based on Institute of Electrical and Electronics Engineers' (IEEE) 802.11 family of standards [24] that enable wireless Internet connection as well as ad-hoc communication between devices. In the first scenario, Wi-Fi client devices connect to the Internet via access points (APs), while in the second scenario they establish ad-hoc network in which devices communicate in a peer-to-peer (P2P) manner. Wi-Fi is suitable for wide range of applications, including higher data rate examples such as video streaming, on a wide range of devices (e.g., laptops, smartphones, sensors). The channel access in 802.11 is CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) as opposed to the frequency hopping of BLE. Achieved data rates vary depending on the standard, with value of 54 Mbit/s and range of 30 m for 802.11g, compared to 1 Mbit/s and 50 m of BLE.

UMTS is a third generation (3G) mobile network standard developed and maintained by the 3GPP. It is based on a Global System for Mobile Communications (GSM) standard. Over the years UMTS has introduced several backwards compatible technological releases, each bringing upgrades and new features, such as new modulation schemes, protocol support, or air interfaces. Earliest release from 2001, based on Wideband Code Division Multiple Access (W-CDMA), offered a maximum downlink throughput of 384 kbit/s, while newer High Speed Downlink Packet Access (HSDPA) release 5 theoretically enables 7.2 Mbit/s. Unlike Bluetooth and Wi-Fi, UMTS is dominantly used as a wide area solution.

IV. Measurements for Energy Consumption Model

Our energy consumption model is based on measurements in which we used Bluetooth 4.0, Wi-Fi, and 3G wireless communication technologies at a full load. The process of designing our energy model can be divided in three phases. The first phase consists of measuring and collecting several parameters like the amount of transferred data, percentage of available battery, and elapsed time. In the second phase we made a comparison between the collected data. For each wireless technology we compared a maximum specified data throughput with a real world data throughput. In the third phase, based on the measured data, we designed energy consumption model for each of the communication technologies above. In our previous work [12] we made an energy model for Android phones as opposed to the model proposed in this paper that is based on iOS phones. Moreover, in this model we included the measurements of Bluetooth 4.0 standard that is present on today's iOS phones.

A. The first phase – Measuring and collecting parameters

For the purpose of measuring data we developed two iOS applications. The first iOS application communicates with web server downloading or uploading data using Wi-Fi and 3G technologies. It transfers the data continuously until battery percentage drops for 5%. During communication with the web server, application measures the following parameters: amount of transferred data, battery status, and elapsed time. The second iOS application communicates with another iOS device using Bluetooth 4.0. One iOS device is in a peripheral mode and it sends data to another iOS device which is in a central mode. These applications also communicate continuously until battery percentage drops for 5% on both devices. All measurements are performed on iPhone 5 smartphone devices.

B. The second phase – Comparison of collected data

In the second phase we compared the measured data. Figure 1 shows the amount of downloaded and uploaded data depending on energy consumption when using Wi-Fi, 3G, and Bluetooth 4.0. The biggest amount of data was transferred using Wi-Fi. The result shows that it was downloaded 390.62 MB and uploaded 65.53 MB of data. When using 3G, 175.67 MB of data was downloaded and 20.19 MB uploaded. The lowest amount of data transfer was achieved with Bluetooth 4.0, only 4.63 MB in download and 3.64 MB in upload.

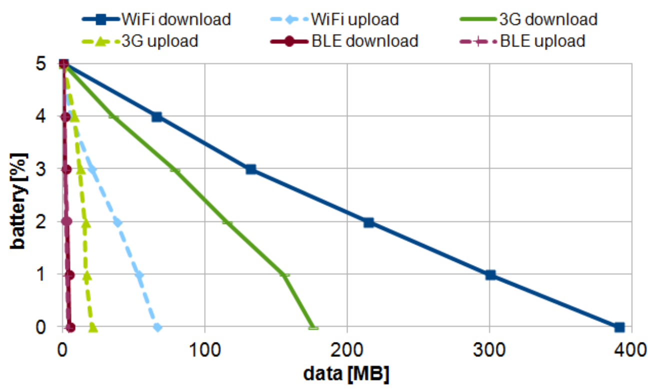

Fig. 1. Amount of data compared to energy consumption

Figure 2 shows the elapsed time compared to the energy consumption using Wi-Fi, 3G, and Bluetooth 4.0 wireless communication technologies. We can see that Bluetooth 4.0 consumes less energy than Wi-Fi and 3G. File upload using Bluetooth 4.0 lasted 23.79 minutes and file download lasted for 19.82 minutes. File transfer using Wi-Fi lasted slightly less than Bluetooth 4.0 but amount of transferred data was much higher. From Figure 2 we can conclude that 3G consumes significantly more energy than Wi-Fi or Bluetooth 4.0.

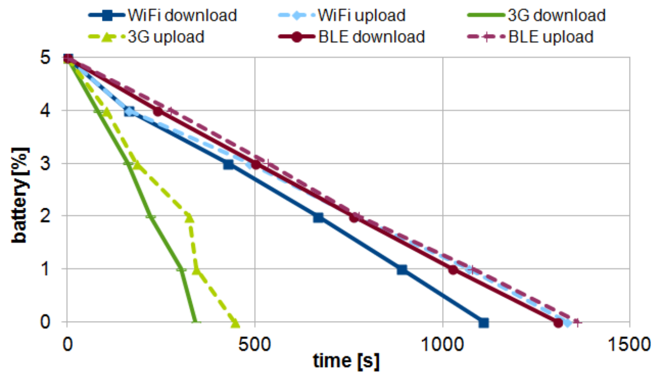

Fig. 2. Amount of elapsed time compared to energy consumption

Combining the measured data from Figure 1 and Figure 2, we can calculate throughputs for each wireless communication technology. A maximum theoretical throughput of Bluetooth 4.0 is 1 Mbit/s, while our result showed that the real world throughput is only 0.03 Mbit/s in downlink and 0.02 Mbit/s in uplink. The real world throughput is significantly smaller than the theoretical throughput because iOS has a limit of sending data in chunks of 20 bytes. For Wi-Fi measurements we used 802.11g network that provides Internet access with maximum throughput of 4 Mbit/s in downlink and 512 kbit/s in uplink. Our measured throughput for Wi-Fi was 3.22 Mbit/s in downlink and 430 kbit/s in uplink. Finally, for 3G we used a HSDPA mobile network that provides Internet access with a maximum throughput of 7.2 Mbit/s in downlink and 1.4 Mbit/s in uplink. Our results showed that the actual throughput was 4.32 Mbit/s in downlink and 0.38 Mbit/s in uplink.

C. The third phase – Energy consumption model

In the third phase we collected and processed the measured data. Based on the collected data, we designed an energy consumption model. Table I shows energy consumption functions in respect to the transfer time and transferred data when using Bluetooth 4.0, Wi-Fi, and 3G communication technologies for downloading and uploading data.

TABLE I. Energy consumption functions in respect to transfer time and transferred data

	Download		*Upload*	
	time [min]	data [MB]	time [min]	data [MB]
Bluetooth 4.0	y = 0.23x	y = 1.08x	y = 0.221x	y = 1.374x
Wi-Fi	y = 0.271x	y = 0.013x	y = 0.226x	y = 0.076x
3G	y = 0.88x	y = 0.026x	y = 0.676x	y = 0.248x

V. QOS IN M2M SERVICE PROVISIONING PROCESS

Since in an M2M system there are devices that can communicate using multiple technologies, M2M service providers (M2M SPs) can offer to those devices the same service but with different QoS. This can be done if in a service provisioning process, information about used communication technology is leveraged. For example, if one device can communicate both using Bluetooth 4.0 and 3G, an M2M SP can offer to that device the same service with two different QoS depending on which technology it wants to use.

Our proposed QoS metric will be presented on an example M2M service that enables a photo upload in search & rescue missions. Generally, our proposed metric can be used on any M2M service for transferring any kind of data when multiple communication technologies are available. Cameras that are taking photos are positioned on autonomous vehicles which reconnoiter ruins made by earthquake, underwater for victims of a ship wreck, or rooms of a building on fire. Photos have to be transferred as soon as possible to the rescue mission centre where they are analyzed. If people are spotted, rescue teams will be sent to that area. Since autonomous vehicles in those conditions are in an area with low signal coverage, it is important that they support multiple communication technologies. Also, in the case of longer search missions, power is a limited resource which has to be dealt with carefully. Therefore, we propose a QoS metric which takes into account two parameters: time and energy consumption.

A. *QoS Metric*

The process of transferring the photo consists of two parts, as shown in Figure 3: negotiation part and service part. In the negotiation part, transfer technology is chosen from the available technologies that the machine supports and is able to use at that moment regarding two parameters: time and energy consumption. In the service part, the photo is uploaded using a technology with best QoS at that moment.

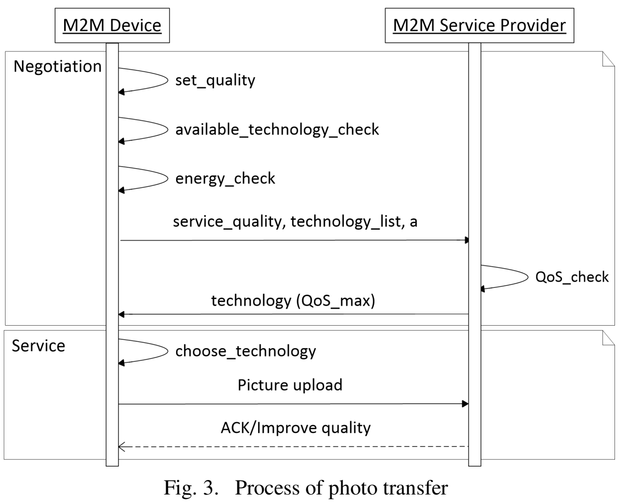

Fig. 3. Process of photo transfer

Negotiation part starts with an M2M device deciding on three parameters: desired quality of the photo, available communication technologies, and parameter a which denotes how important energy consumption is to the autonomous vehicle. These three parameters are then sent to the M2M SP. An M2M device sets the quality of the photo to be as low as possible. The value of the parameter a is appointed from the interval [0, 1]. If the autonomous vehicle carrying the camera is low on energy, the value of the parameter a will be closer to 1. In that case, energy consumption is more important for QoS than upload time. On the other hand, if there is enough energy for reconnaissance and photo transfer, value of a will be closer to 0. In that case, time for upload will have a higher significance in determining QoS. The M2M SP receives aforementioned parameters and uses expression (1) to calculate QoS for each technology supported by the M2M device.

$$QoS = 10\frac{1-a}{t_{CONS}} + \frac{a}{E_{CONS}} \quad (1)$$

A parameter t_{CONS} stands for the average time necessary to transfer the photo of the desired quality using the desired technology. A parameter E_{CONS} stands for the energy necessary to transfer the photo of the desired quality using the desired technology. We consider transfer time to be of a higher importance to QoS than energy, because of that we introduce factor 10 to be multiplied with the first expression. QoS parameter is calculated for every technology received in a *technology_list* parameter from the M2M device. Technology with the highest QoS value is sent back to the device from the M2M SP and will be used for the photo transfer. In the service part of the transfer, the photo is sent from the device to the M2M SP. The response to the received message is ACK message or request to improve quality. As mentioned earlier, the device sets the quality of the photo to be as low as possible. If M2M SP deems the quality to be too low, it sends request for quality improvement.

B. *QoS Measurement*

We measured the QoS while sending a photo using different wireless communication technologies. For the purpose of measuring QoS parameters we developed an iOS application which can upload a photo taken from iPhone's camera to the web server or send it to the computer. Before uploading the photo to the web server or sending it to the computer, it was encoded with JPEG encoder. We used Wi-Fi and 3G to upload the photo to the web server and Bluetooth 4.0 to send it to the computer which had a Bluetooth 4.0 dongle.

Three different levels of JPEG compression simulated different qualities of the photo an M2M device can choose. In our measurements we used a device (iPhone 5) with three different communication technologies and chose three different values of the parameter a: 0.25 which denotes that there is enough battery and goal is to achieve faster upload (i.e., shorter time), 0.75 which means that battery is low on energy, and 0.5 if the device is indifferent of the elapsed time or battery status. Results of measurements are shown in Table II. The best transfer time is achieved by using Wi-Fi and 3G at the highest compression rate. However, the photo quality in those scenarios is low and it is possible to see artifacts on the photo. QoS values are calculated for transferring photo with compression of 33%. Wi-Fi achieved best QoS value due to best transfer time and smallest energy consumption. Moreover, it is interesting to note that QoS for 3G deteriorates a bit faster than for Wi-Fi. Bluetooth achieved weakest results because iPhone's constraint to send data in 20 byte packets proved inefficient solution for tested scenarios.

TABLE II. QoS METRIC FOR DIFFERENT SCENARIOS

JPEG compression	*66%*	*33%*	*Original photo*	*Value of the parameter a*		
Data [MB]	2.6	4.6	7.3	*a_1 = 0.25*	*a_2 = 0.5*	*a_3 = 0.75*
Wi-Fi Download						
Time [s]	5	9	15	**QoS = 56.25**	**QoS = 45.83**	**QoS = 35.42**
Energy consumption	0.02%	0.04%	0.07%			
Wi-Fi Upload						
Time [s]	42	98	127	**5.27**	**4.41**	**3.56**
Energy consumption	0.15%	0.37%	0.48%			
3G Download						
Time [s]	5	10	16	**46.67**	**33.33**	**20**
Energy consumption	0.07%	0.15%	0.23%			
3G Upload						
Time [s]	64	115	181	**4.11**	**3.00**	**1.89**
Energy consumption	0.72%	1.29%	2.04%			
Bluetooth 4.0 Download						
Time [s]	699	1290	2118	**0.40**	**0.33**	**0.27**
Energy consumption	2.68%	4.94%	8.11%			
Bluetooth 4.0 Upload						
Time [s]	944	1683	2680	**0.31**	**0.26**	**0.21**
Energy consumption	3.47%	6.19%	9.85%			

VI. CONCLUSION

In this paper we discussed the problem of defining a Quality-of-Service (QoS) metric for Machine-to-Machine (M2M) devices that support multiple communication technologies. This is a new research challenge because in one network both wireless and wireline network accesses are supported. In this paper we defined a QoS metric that includes both energy and time consumption aspects of M2M services. In order to use the proposed metric, we measured the energy consumption for different communication technologies of iOS device and proposed an energy consumption model for iOS devices. In this paper we have not considered other parameters for QoS such as delays or packet losses that may also have a big impact on some specific applications. Thus, we plan to cover these topics in future work.

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