MACHINE-TO-MACHINE COMMUNICATIONS TOWARD SMART LOGISTICS SYSTEMS

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Abstract: *Transport and logistics companies face continuous competitive pressure to maximize capacity and improve efficiencies of their infrastructure as well as to meet the increasing governmental regulation and compliance demands. Deployment of new communications technologies, e.g. cloud computing, Internet of Things (IoT) and Machine-to-Machine (M2M), represents a prospective solution for achieving these objectives. Owing to low power, cost efficiency and low human intervention, M2M communication has become a main driving force for a number of wide variety of real-time applications. The expected huge number of interconnected devices and the significant amount of available data open new opportunities to create services that will bring tangible benefits to the logistics companies, as well as to the end users. This paper represents a comprehensive survey on M2M communications considering some open research issues and challenges toward the realization of smart logistics systems.*

Keywords*: Logistics systems, M2M communications, mobile networks.*

1. INTRODUCTION

Machine-to-machine (M2M) communications have emerged as a paradigm which provides ubiquitous connectivity among devices (objects) without human intervention. The main idea of M2M communications is to enable mechanical and electrical components to be interconnected, networked, and controllable remotely, with low-cost, scalable, and reliable technologies. Current market penetration and recent predictions confirm that M2M system deployments are increasing exponentially (Cisco, 2014). This is driven by the needs of industries to automate their real-time monitoring and control processes as well as the increasing popularity of smart applications to improve the living style.

Achieving better cost efficiency, M2M communications has become a market-changing force for a wide variety of real-time applications, such as smart environments, industrial control, security and emergencies, e-healthcare, transport and logistics, etc. In Vodafone (2014) report, transport and logistics are considered as prospective leaders in the use of M2M communications, taking into account significant benefits of implementation. According comprehensive market research, 12% of all companies in this field already deployed some solutions of M2M communications. Moreover, the fact that great majority of them (67%) achieved significant return of their investments for a very short time, is of great importance. Major benefits of M2M communications deployment in transport and logistics sectors can be identified as cost reduction, better customer service, business agility, improved productivity, consistency of delivery across markets, etc. Generally, M2M communications can be observed as promising technological tool for optimization of complex industrial processes.

This paper is organized as follows. First, general end-to-end architecture for M2M communications is presented. Then we focus on some specific properties of M2M communications which are of importance for applications of M2M systems in logistics services. Finally, prospective solution for realization of M2M communications over mobile networks is presented.

2. GENERAL NETWORK ARCHITECTURE FOR M2M COMMUNICATIONS

The characteristics of M2M communications are quite different from those of conventional networks (Kim et al., 2014). M2M networks are composed of large numbers of nodes, since the main subject participating in communication is a machine (device). Because most devices are battery operated, energy efficiency is the most important issue. As for the machine senses, itself or its surrounding physical environment, the traffic generated by device is very small. However, data are generated from a large number of objects, and because the data generation period, amount, and format are all different, a large quantity of data is generated. While M2M communication can occur without human intervention, operational stability and sustainability are also required.

In 2009, the European Telecommunications Standards Institute (ETSI) has established the M2M Technical Committee with the purpose to develop an end-to-end architecture for M2M communications. According to ETSI, an M2M system is composed of the five key elements with following functions:

- M2M component, embedded in a smart device, transmits data or replies to requests.
- M2M gateway enables connectivity between the M2M components and the communication networks.
- M2M server works as a middleware layer to pass data through various application services.
- M2M area network provides connectivity between M2M components and M2M gateways.
- M2M communication network provides connection between M2M gateways and M2M servers.

These key elements constitute the general M2M communication architecture in the three interlinked domains, i.e., the M2M device domain, network domain and application domain as shown in Fig. 1.

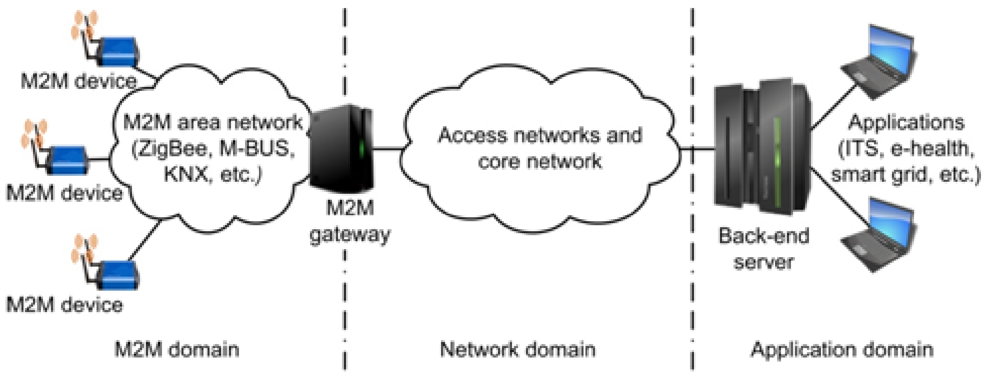

Figure 1. General M2M communication architecture

In the M2M domain, a potentially large number of nodes and M2M gateway (GW) are integrated to enable automated and diverse services. Each embedded node as flexible and smart device should be equipped with various functions, such as data acquisition, data preprocessing, data storage, distinctive address, communication interface, power supply, etc. They can make intelligent decision and transmit the sensory data to the GW in single-hop or multihop manner. The M2M GW is an integrated device. After collecting the packets from embedded nodes, it is able to intelligently manage the packets and provide efficient paths for forwarding these packets to the remote back-end server via wired/wireless networks.

In the network domain, a large number of heterogeneous points of attachment potentially coexist. Here, convergence of heterogeneous networks in an optimal way provides cost-effective and reliable channels for sensing data packet transmission from M2M to the application domain.

Finally, in the application domain, various real-time services for remote management monitoring are provided and can be classified into several categories, such as traffic, logistics, business, home, etc. Back-end server is the key component for the whole M2M communication system. It forms the integration point for all collected data from M2M device domain.

M2M devices can be either stationary (e.g., smart meters at homes, vending machines, etc.) or mobile (e.g., fleet management devices in vehicles, e-health sensors, etc.). The access networks connect M2M devices to the core network using either wired or wireless links. Although the wired solution can provide higher data rates, reliability, security and low latency, it may not be adequate for the all M2M applications due to it cost ineffectiveness, lack of scalability and mobility support. Wireless access can be either capillary/short range (e.g., ZigBee, Bluetooth, Wireless Fidelity - WiFi, etc.) or cellular (e.g., Long Term Evolution - LTE, Worldwide interoperability for Microwave Access - WiMAX, etc.). Wireless capillary solutions, mainly used for shared short range links, are rather cheap to roll out, and generally scalable. However, small coverage, low data rates, weak security, severe interference, and lack of universal infrastructure pose restriction on their applications to M2M communications. On the other hand, mobile systems offer wide coverage, mobility support, satisfactory security, and ready-to-use infrastructure, making cellular networking a promising solution for M2M communications. Therefore, current and next generation mobile systems (i.e., LTE and LTE-Advanced) are in the main focus of recent researches as stated by Ghavimi and Chen (2015).

3. PROPERTIES OF M2M COMMUNICATIONS AND APPLICATIONS IN LOGISTICS SERVICES

The properties of M2M communications are quite different to traditional human-based communications. While human-to-human (H2H) and human-to-machine (H2M) communications obey a certain session length, data volume and interaction frequency, M2M communications follow some very specific traffic properties. M2M devices generate heterogeneous traffic patterns, including periodic (uniform), event-driven (stochastic), and multimedia streaming (heavy tailed), depending on their applications. These various traffic patterns are generated by the massive number of nodes, which have different patterns, generation periods, and generated intensities. As most of M2M devices are reporting sensor data, such as temperature, pressure, humidity, etc., the transmitted packets consists of the measured data plus the corresponding protocol overhead. In general, this overhead is kept as small as possible, whereas the actual payload differs according to its application. Although the expected intensity of generated traffic per device is relatively low (in order of few kbit/minute) the share of M2M traffic will soon exceed 5% of global Internet traffic, having in mind huge number of devices.

The combination of M2M communications and intelligent objects can largely improve the supervision of logistic processes (Palafox-Albarran et al., 2012). With an increasing number of vehicles on the road, the transportation and logistics services will become big market for M2M communication technology. Vehicles equipped with M2M sensors and actuators, become M2M communication entities. Furthermore, roads and transported goods use M2M sensors and tags (e.g., Radio Frequency Identification - RFID and Near Field Communication - NFC) that can also send valuable information to the M2M control centers and logistics companies to route the vehicles, monitor the status of the transported goods, seamlessly track the physical locations of fleet vehicles, and deliver updated schedule information to customers.

Today, a large number of container cargo ships are traveling through international waters. These container cargo delivery services may risk theft, physical damage, delivery delays, piracy, and even ship sinking. M2M technology provides solutions that are being used in fleet management to acquire a better control where cargos can be rapidly delivered across different continents. The M2M applications enable the tracking of vehicles and cargo containers to collect the data on locations, fuel consumption, temperature, and humidity, in order to increase fleet safety, reduce the accident rates, and increase the productivity of a logistics company. With more precise information, greater control, better resource management, and higher cost effectiveness, a fleet business can be able to maintain its competitiveness with the help of M2M technology.

Goods supply chain can work in a more efficiency way as M2M communications provide possibility to track the status of goods in real-time. The M2M logistics enables ubiquitous surveillance on the status of products, raw materials, transportation, storage, sale of products, and aftersales services by keeping an eye on temperature, humidity, light, weight, etc. If the status has some problem, the M2M devices can automatically send an alert to the M2M server via the LTE/LTE-A core network. Furthermore, it is also possible to track the inventory in a warehouse so that stockholders and enterprises can respond to the market dynamics and to decide when to refill and when to go on sale. Therefore, this can significantly reduce the size of warehouse, the waiting time of customers, and the number of the employees in order to save the operational costs for business entities.

4. HIERARCHICAL CELLULAR-CENTRIC M2M ARCHITECTURE

As previously stated, cellular networks are considered as a prospective solution for M2M applications, especially for high mobility services such as smart transportation systems and logistics. Current M2M solutions already use second and third generation (2G, 3G) of mobile networks, but with expected exponential increasing of M2M devices density and consequently traffic intensity, their capacity will soon be overcome. Thus, implementation of M2M communications in next generation cellular systems (i.e., LTE/LTE-A) is unavoidable. Moreover, M2M communications are declared by Boccardi et al. (2014) as one of the five disruptive technology directions for the fifth generation (5G) mobile networks. Recently, flagship standardization bodies in this field, Third Generation Partnership Project (3GPP, 2012) and Institute of Electrical and Electronics Engineers (IEEE, 2012) have introduced some enhancements of cellular systems architecture in order to support M2M communications.

Based on ETSI general architecture, complemented with 3GPP LTE-A and IEEE 802.16p enhancements, it is possible to define a cellular-centric architecture proposed by Lo at al. (2013). It can provide useful reference architecture for designing a complete M2M communications system. As shown in Fig. 2, the resulting M2M network architecture is hierarchical, consisting of four tiers. First tier consists of the M2M application (M2M-A) services and server (M2M-S). In second tier, a new functional entity M2M relay (M2M-R) is introduced. M2M-R is an extension of the conventional LTE-A relay functionality and can be used as an M2M data aggregator. In this case, M2M-R aggregates data units from multiple M2M devices (M2M-Ds) into a single large packet for transmission to the same or different M2M-Ss. M2M-R increase system capacity and, more importantly, reduces transmission power of M2M-Ds that have power constraints. At third tier, the M2M gateway (M2M-G) ensure M2M-Ds interworking and interconnection to the M2M network domain. Unlike M2M-R, the M2M-G supports multi-radio access technologies (e.g., RFID, ZigBee, low power Bluetooth, WiFI, etc.) in addition to LTE-A. In principle, the M2M-G can assume the role of M2M-R. However, such a solution might not necessarily lead to optimal performance because the deployment of M2M-G is dictated by the coverage of the supported wireless technologies. On the other hand, an M2M-R can be strategically deployed to achieve good coverage and signal quality, resulting with better quality of service. Typically, an M2M-R can be positioned to attain line-of-sight with the LTE-A evolved node B (eNB). Thus, legacy (non-3GPP compliant) M2M-Ds are connected to the M2M-G at fourth tier, while low mobility, power and location-sensitive 3GPP M2M-Ds are connected to M2M-R at upper tier. Furthermore, M2M-Ds and M2M-Gs with high mobility requirements are directly connected to the LTE-A eNB at second tier.

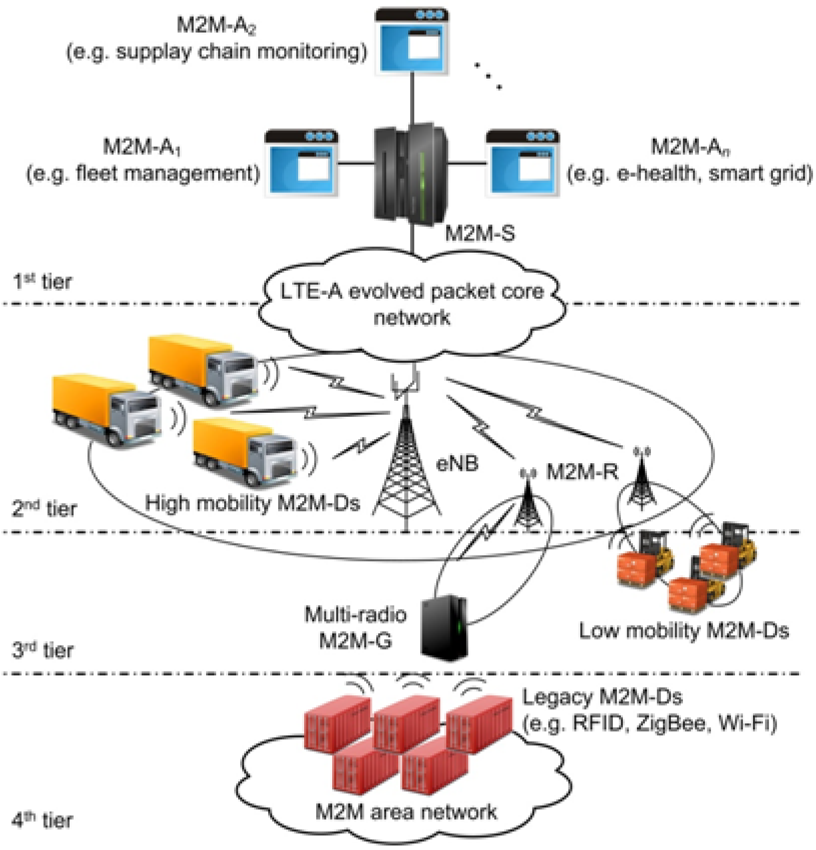

Figure 2. Hierarchical cellular-centric M2M architecture

When an M2M-A data unit is sent from the M2M-D to the M2M-S, every protocol layer on each network entity adds its own header. In addition to the entity headers, IP-in-IP tunneling established between M2M-R and eNB, and between eNB and core network adds three protocol headers (i.e., network, transport, and tunneling). This means a significant portion of the bandwidth is wasted on transmitting overheads, thus reducing spectral efficiency. It is shown by Lo et al. (2013) that in the worst case, the total overhead consumes more bandwidth than the actual M2M-A protocol data unit. Although eNB incurred the highest overheads, the overhead problem is more pronounced on the M2M-R to eNB transmission than on the eNB to core network link due to limited frequency spectrum. Moreover, M2M-Ds share the frequency spectrum with the mobile terminals. However, the overhead problem cannot be neglected when the eNB serves several M2M-Rs, and each of which serves a large number of M2M-Ds.

Rational solutions for solving considered problem are mainly related to the traffic aggregation. In research provided by Lo at al. (2013) a tunnel-based data unit aggregation scheme is proposed. M2M-A data-unit aggregation entity can be introduced at M2M-R, eNB, core network, as well as at M2M-G. Data units are classified into two distinct classes, high and low priority. An outgoing first-in first-out (FIFO) queue is defined for each of them. The high priority queue buffers delay-sensitive data units (e.g. accident events), while delay-tolerant data units (ordinary reports) are placed in the low priority queue. Obtained results show a significant reduction in protocol overheads using aggregation scheme since LTE-A is optimally designed for H2H communication. Although aggregation causes data-unit delay, it rapidly decreases as the number of M2M devices increases. On the other hand, Ahmad et al. (2014) proposed a methodology for facilitation of logistic processes by exploiting the M2M-R functionality for aggregation and multiplexing of M2M data traffic. By integrating traffic demands from several M2M devices in a single physical resource block, system performance can be considerably improved in terms of lower delay and higher throughput, in comparison to the case of unaggregated M2M traffic. In this approach, traffic classification is not considered, so it seems that increased delay can be expected for stochastic (i.e., event-driven) demands such as emergency and accident events.

5. CONCLUSION AND FUTURE WORK

It is obvious that convergence of M2M communications and logistics services is one of the pillars of the IoT environment. The expected benefits are significant for both, telecommunication operators and logistics companies. In this paper some specific properties of M2M communications which are of importance for applications of M2M systems in logistics services are emphasized. Having in mind these characteristics and fact that mobile systems offer wide coverage, mobility support, satisfactory security, and ready-to-use infrastructure, hierarchical cellular-centric architecture is analyzed as a prospective solution for M2M-driven logistics services. Moreover, challenging issue regarding overhead problem is noted, and some rational solutions based on traffic aggregation are presented. As main direction of future researches, M2M traffic characteristics and comprehensive simulation analysis of their influences on mobile network performances are envisaged.

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