Converged Mobile Cellular Networks and Wireless Sensor Networks for Machine-to-Machine Communications

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Abstract

In recent years, machine-to-machine (M2M) communications are under rapid development to meet the fast-increasing requirements of multi-type wireless services and applications. In order to satisfy M2M communications requirements, heterogeneous networks convergence appears in many areas, i.e., mobile cellular networks (MCNs) and wireless sensor networks (WSNs) are evolving from heterogeneous to converged. In this paper, we introduce the system architecture and application requirement for converged MCN and WSN, where mobile terminals in MCN are acting as both sensor nodes and gateways for WSN. And then, we discuss the joint optimization of converged networks for M2M communications. Finally, we discuss the technical challenges in the converged process of MCN and WSN.

Keywords: M2M communications, MCN, WSN, converged networks

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1. Introduction

Wireless communication technologies have been under rapid development during recent years. Types of wireless communications have been developed from the single wireless network coverage to multiple wireless network joint coverage, i.e., mobile cellular network (MCN), wireless personal area network (WPAN) or wireless local area network (WLAN) can cover the same area for wider applications. In order to satisfy fast-increasing M2M communications requirements, multiple wireless networks convergence has become the trend [1][2]. The concept of internet of things (IoT) based on WSN and MCN [3], have also enormously promoted the development of Machine-to-Machine (M2M) communications. Generally, M2M is based on very common and ubiquitously used technologies – WSN and MCN, which usually uses the cellular system as the backhaul networks [4].

Heterogeneous networks consisting of MCN and WSN appear in many application areas such as electricity, transportation, industrial control, e-health, environment monitoring, et al. In China, many researchers are attempting the integrated technology of combining WSN with time division-synchronous code division multiple access (TD-SCDMA) technologies to provide M2M communications, where many dedicated mobile terminals of MCN are equipped with WSN air-interface and can provide backhaul data links for the WSN. International telecommunication union (ITU) has also proposed the M2M communications for the next generation network [5]. According to the ITU recommendation, 3GPP (3rd Generation Partnership Project) is drafting the standards about machine-type communications (MTC) based on universal mobile telecommunications system (UMTS) and long term evolution (LTE) networks [6]. 3GPP identified M2M (also called MTC) as a strategic topic in 2007. 3GPP standards in the M2M domain are mostly connection improvements in radio access networks (i.e. TR 43.868, TR 37.868), which are standardized by RAN WG2 and GERAN WG2. Another group of standards is mainly in charge of potential requirements in M2M communication and network resources efficiency improvement (i.e. TR 22.368, 22.868 and TR 22.988). The ETSI (European Telecommunications Standards Institute) also constructs a new ETSI Technical Committee to develop standards for M2M Communications. This group aims to provide an end-to-end view of M2M standardization, which is cooperating with 3GPP for mobile communication technologies [7]. For M2M communication, ETSI standards mostly consider different use cases (i.e. TR 102 691/732/898 *et al*). Nevertheless, some efforts have been put forward in defining M2M concepts (i.e. TR 102 725), as well as in standardizing M2M service requirements (i.e. TS 102 689) and functional architecture (i.e. TS 102 690).

In the whole M2M communication system, WSNs are the front sensing part, which can be flexibly deployed to detect different types of data, and then MCN can send data wirelessly to a central web service center. In the conventional network architecture, MCN and WSN is hierarchical and integrated, where the gateway is just a data channels and are implemented to exchange information between the two independent stacks. In the converged MCN and WSN, MCN can be used in the supervisory control for WSN data transmission system, where the nodes of WSN can overhear the downlink signaling from the MCN directly. WSN in the applications can be managed and optimized with the aid of MCN. Because MCN has the advantages of large coverage and powerful user terminals, MCN and WSN convergence is indispensable for supporting M2M communications [8][9]. The convergence of MCN and

WSN can also benefit each other: (I) For WSN, the MCN can provide optimization to prolong the WSN life time, provide quality of service (QoS) for WSN services; (II) For MCN, WSN can extend the intelligent application range of MCN, i.e. WSN can provide real-time measurement results to MCN users [10]. Hence, the convergent interactive control and joint optimization technologies of MCN and WSN need to be researched and developed.

In this paper, we first provide an overview in the evolving process of converged network for M2M communications based on MCN and WSN convergence. Then, in Section II, we describe the system architecture and requirements for M2M communications. In Section III, we introduce the joint optimization of MCN and WSN for QoS guarantee, where the mobile terminals acting as both sensor nodes and gateways. Moreover, a comprehensive system research issues and technical challenges analysis is given in Section IV. Finally, we conclude our work in Section V.

2. System Requirements

The M2M networks applications are service-oriented. At this point, gateway is important equipment for realizing the interconnection between WSN and MCN [11]. We mention two types of gateway: fixed gateway and mobile UE gateway. In this scenario, the UE gateway is dual-mode and provides with both WSN and MCN interfaces. The eNodeB is the base station of the cellular networks. Then, the data from WSN can be directly forwarded to the eNodeB by the UE gateway as shown in **Fig. 1**. The mobile UE gateway can also acquire the necessary information with the downlink transmission from the eNodeB and forward this to the WSN directly. One of the major system requirements is how to select a proper wireless connection protocol that achieves at least the minimum requirements of the M2M sensing networks (also called WSN). The other is the application requirements for the M2M communications.

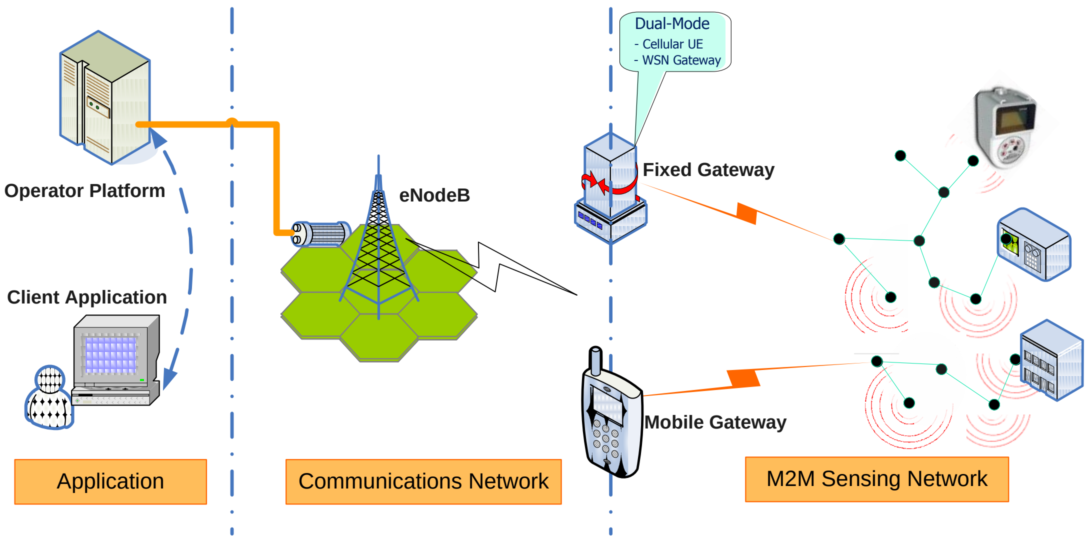

Fig. 1. M2M system architecture

2.1 WSN communications technology requirements

Since WSNs tend to have a larger variety of applications, different communications technologies can be used for WSN, such as WiFi, Bluetooth, UWB and Zigbee

[12][13][14][15]. Since IEEE 802.11 technology lacks a low-power mode, it is not suitable for the low-powered and highly integrated WSN. The IEEE 802.15 working group provides standards for low-complexity and low-power consumption wireless connectivity at physical (PHY) and media access control (MAC) layers. **Table 1** shows some figures about the WSN system parameters such as the delay and throughput by using the different wireless technologies.

Table 1. Characteristics of WSN communications technologies

Feature	**WiFi (IEEE 808.11x)**	**Bluetooth (IEEE 808.15.1)**	**UWB (IEEE 808.15.3)**	**ZigBee (IEEE 808.15.4)**
Range	<100m	<10m	<10m	10-100m
Data rate	11a < 54 Mb/s 11b < 11 Mb/s 11g < 54 Mb/s	1-3Mbps	480 Mbps with impulsive radio	20, 40 and 250 kbps
Operating frequency	11b/g: 2.4GHz, 11a: 5GHz	2.4 GHz	3.1-10.6 GHz	868 MHz, 915 MHz, 2.4 GHz
Network Size (nodes)	Few, depends on interference and achieved data-rate	2 up to 8 per piconet	2	<65536
Scalability	No	No	-	Yes
Battery life	Hours or access points connecting with power supply	a week	a week	>1 year
Data type	Video, audio, graphics, pictures, files	Audio, graphics, pictures, files	Video, audio, graphics, pictures, files	Small data packet
New slave connect	Up to 3 s	Up to 10 s	-	30 ms

WiFi is mainly used for high data rate transmission in wireless internet connection. WiFi technology allows different devices like laptops, personal computers (PCs), cell phones, and personal digital assistants (PDAs) to communicate between one another or to connect to the Internet without needing a cable connection. There are different standard versions known as IEEE 802.11x (a, b, or g), which are available in one chip. WiFi network protocols are operating in the unlicensed radio bands of 2.4GHz and 5GHz. WiFi certified device can operate with data rates of 11Mbps for IEEE 802.11b or 54 Mbps for IEEE 802.11a [16]. The greater the distance to the access point, the lower the performance. However, WiFi technology lacks a low-power mode, and its lifetime cannot be very long without the power supply. Thus, a low-powered WSN cannot use this technology.

Bluetooth technology has a low-power mode and operates in the unlicensed 2.4GHz band, which is a suitable choice for convenient, wire-free, short-range communications between devices. The Bluetooth wireless communications technology provides a personal area network (PAN) for exchanging data between Bluetooth-capable devices within certain proximity. The main objective of Bluetooth was to replace the wired connections between personal devices (such as mobile phone, digital camera, etc), which can deliver relatively high data rate (about 1 Mb/s - 3 Mb/s) [17]. But the Bluetooth networking capabilities are not strong enough for large networks and it is limited to short-distance communications. For this reason, Bluetooth is just mentioned and described as an existing technology for developing WSN.

The Ultra Wideband (UWB) technology allows information to be transmitted at a large bandwidth in precise pulses that are typically 1 to 2 nanoseconds in length and occupy at least 25% of the center frequency, much more than other systems. UWB is a proposed as a solution for huge data rate transmission in very short distances (<10 meters). The data rate can be as high as 480 Mb/s or even much more. The use of this technology is limited to the frequencies range from 3.1 to 10.6 GHz. Its remarkable characteristic is its better interference than other technologies, nevertheless, UWB transmission range is limited [18]. Besides the transmission distance, the frequency (3.1-10.6GHz) is another main reason for not going into normal WSN research.

ZigBee is established by the ZigBee Alliance, which added flexible network, security and application protocol to IEEE 802.15.4 standard. The Zigbee transmission range is expected to be up to about 100 m. ZigBee can operate in unlicensed bands, such as 868 MHz, 915 MHz and 2.4GHz, with transmission rates of 20, 40 and 250 kbps [19]. These are relatively low rates compared to the WiFi and Bluetooth protocols, but they are adequate for their service applications in the M2M sensing process. The ZigBee technology is a communications standard for systems with requirements such as long battery life, low data rates, secure communications, and less complexity compared with previous wireless standards. Owing to its low power consumption and simple networking configuration, ZigBee is considered the most promising for WSN.

2.2 Application requirements

Besides the transmission technology requirements, different service applications of WSNs have different requirements, such as data accuracy, reliability, latency, etc. WSN Data delivery models can be divided in to three types: periodical, event-driven and query-driven [20][21]. In the periodical model, sensor nodes continuously send the detected data to the sink gateway at a pre-specified period. Most query-driven applications in WSNs are required by the remote user in application layer, which is interactive, query-specific delay tolerant. Most event-driven applications in WSNs are emergent data, which are delay intolerant, mission critical and non-end-to-end applications. The detailed applications and services requirements are shown in **Table 2** [22][23][24][25][26][27].

Table 2. Application requirements

Applications	Requirements
e-Health care: Monitoring vital signs Web Access Telemedicine points Remote diagnostics	1. Guarantee different delivery types having different delay and packet loss level, and emergency communication has the highest priority. 2. Avoid access concentration to a single channel resource. 3. Need to ensure the simultaneous mass data transmission.
Metering: Power Gas	1. Monitored and controlled by a central web server. 2. The central server needs to inform or control the metering device when it needs measurement

Water Heating Grid control Industrial metering	information. 3. The network should be optimized to enable a mass of sensors in a particular area to transmit data simultaneously. 4. Due to the UE gateway moving, sensor nodes should be able to communicate with the low-speed moving UE. 5. It should have the ability to perform secure transactions. 6. The system should support mutual authentication and authorization between the end-user and the application.
Remote Monitoring/Control: Environments surveillance Pumps surveillance Pollution and disaster surveillance	1. Located in remote areas and can work for years in rigorous environments. 2. Satisfy the user query-driven application. 3. The system should enable to control sensor nodes working state, e.g. change sleeping mode to working mode.
Security: Surveillance systems Theft/Vandalism application	1. Need to alarm in time when it is invaded by unauthorized persons. 2. Need to report and display probable location of the invaded spot. 3. The system can control the sensor nodes state.
Tracking & Tracing: Traffic information Road tolling Road traffic optimization/steering	1. Sensor nodes should be able to provide moving tracking and approximate location. 2. If the entity moving, the sensor nodes should be able to communicate with other communication module. 3. The sensor nodes and its transmission module can work in rigorous environments.

The future M2M networks should be service-oriented. Various M2M applications are applying to extensive areas such as electricity monitoring, intelligent transportation, automatic industrial control, remote healthcare and environment monitoring, et al. In the converged MCN and WSN based M2M communications scenarios, remote sensors gather data and send to a mobile UE gateway, which is also a mobile terminal of MCN and connected to MCN directly. To achieve full convergence of MCN and WSN, the following joint optimization and technical challenges need to be overcome.

3. Joint Optimization of Converged MCN and WSN

In the converged MCN and WSN, for MCN, the benefit brought from WSN is mainly in extending applications. On the other hand, WSN system performance can be improved with the help of MCN. The joint optimization is mainly focused on MCN-assisted WSN transmission. In this section, we mainly research the gateway selection/re-selection, load balance and emergency data adaptive transmission scheme to improve WSN system throughput, decrease transmission delay, reduce the data packet dropping rate and enhance the network lifetime [28].

3.1 QoS-guarantee architecture

The conventional scheme to guarantee the WSN transmission QoS mainly focus on the routing schemes improvement, i.e., SAR (sequential assignment routing), SPEED (A Stateless Protocol for Real-Time Communication), ReInForM (Reliable Information Forwarding using

Multiple Paths in Sensor Networks), ESRT (Event to Sink Reliable Transport) [29][30][31][32]. The whole WSN QoS architecture is shown in **Fig. 2**, and the converged MCN can make QoS support more challenging to improve the WSN energy efficiency [33].

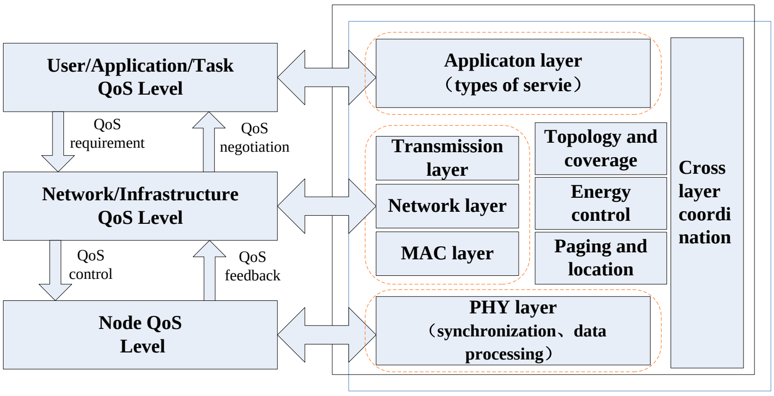

Fig. 2. WSN QoS Architecture

Since WSNs interact with the different environment, the while WSNs bring more QoS challenges. Besides multiple improved routing schemes, certain efficient traffic control and resource management can also guarantee WSN QoS with the help of MCN [34][35]. Their particular characteristics are as follows:

1) Multiple service types: Different applications have different service requirements. Therefore, different types of sensor nodes raise challenges for QoS support. Generally, sensor nodes of monitoring security are more important than those of monitoring environments.

2) Packet criticality: The data packet of different monitor system reflects the criticality of the real application, which has different transmission priority. For instance, some important application types may require higher priority. QoS guarantee mechanisms can be used in this system transmission architecture.

3) Unbalanced traffic: In most applications of WSNs, traffic mainly flows from a large number of sensor nodes to the sink nodes/gateway. Load balance scheme should be designed for unbalanced QoS-constrained traffic.

4) Energy balance: In order to achieve a long-lived network, energy load must be equably distributed among all sensor nodes. If the energy of sensor nodes set in certain area (nearing to sink node) will not be drained out very soon, the whole WSN lifetime can be prolonged.

5) Multiple gateways: There maybe exist multiple gateways in the convergent MCN and WSN to collect the detected data and transfer them to the backhaul networks. Access gateways selection for sensor nodes is a great challenge if the sensor nodes and gateways are not uniformly distributed.

3.2 Access mobile gateway selection/re-selection

In the large coverage area of MCN, there are also many sensor nodes constructing WSN. The UE gateway can provide backhaul access for the WSN nodes. After a UE acting as mobile gateway and entering the coverage of WSN, it may cause the gateway re-selection or even regrouping of the sensor nodes [36]. There are two basic use cases for gateway re-selection: (I)

One is that a new UE gateway enters into a WSN area; (II) The other is that the original UE gateway leaves the coverage area of WSN. In the conventional WSN, when the mobile UE gateway moves into the coverage area of the WSN nodes, they broadcast POLL packets to the WSN nodes, and provide the backhaul access for them [37]. However, when the serving gateway is leaving its responsible area, it won't tell sensor nodes about its leaving in the existing schemes. In this scenario, UE gateway leaving will cause WSN topology of this area reconstruct, which will bring out overhead of the signaling between mobile UE gateway and WSN nodes.

In the converged architecture, how to make a tradeoff between the performance gain and new signaling design in the gateway re-selection and sensor nodes regrouping process is an essential issue for WSN. In the process of UE gateway re-selection, mobile gateway level can be defined as a synthesis of UE gateway's status, i.e. mobility state, probability of leaving, capacity availability, and channel quality etc. Besides this, some extra control signaling is required to design in the cellular interface to realize gateway re-selection process.

3.3 Load balancing for converged MCN and WSN

There may be many UEs which play the role of mobile gateways for WSN. Load unbalance and fast energy consumption of some sensor nodes will appear when one UE gateway has more sensor nodes (high traffic) and its neighbor UE gateway has fewer nodes (lower traffic). In conventional WSNs, the load balance is configured when the network is initiated or the sensor node joins to the sensor network [38]. At first, the entering sensor node broadcasts access-request, and then the sink gateway which received the request sends a reject-ACK or accept-ACK to the sensor node based on its load information [39].

In the convergence system, the UE gateways should report their load information to eNodeB and eNodeB will manage/control the load balance of UE gateways. In the load balance process, load balancing capability should be designed for how many nodes and their services can be balanced to neighbor UE gateway. The load balance command signaling is transmitted by the eNodeB. Energy efficiency is another major concern in the design of WSN's load balance, where dynamic adaptive routing protocol should be designed for data packets optimal transmission.

3.4 Adaptive emergent data transmission

With the application requirement of WSNs used in the emergency monitoring, such as fires, earthquakes, floods. The emergent incident notification must be delivered in a timely and reliable way to the disaster monitoring center [40]. The conventional scheme to guarantee the emergency data transmission mainly focused on the WSN end-to-end routing and MAC backoff algorithm improvement, which transmits this type of data packet by using the highest priority [41].

In the convergent scenario, sensor nodes will use adaptive transmission scheme, which have two types of phases for transmission: normal phase and emergency phase. In normal phase, sensor nodes collect data and transmit it to the gateway by using the WSN router nodes forwarding. When a node enters emergency phase, it will send a seeking beacon signaling with the optimum transmitting power to seek the nearest neighbor UEs gateway, and then UE gateway sends the emergency data to eNodeB with cellular network link directly. Besides the adaptive transmission mode selection, we should research how to adjust transmitting power within interference permission ranges to improve the transmission reliability.

4. Technical Challenges

In the converged MCN and WSN for M2M communications scenarios, a remote sensor gathers data and sends to gateway, where the gateway is also a mobile terminal of MCN. The UE gateway forwards data to eNodeB directly. In order to achieve the convergence of MCN and WSN, the following technical challenges need to be overcome.

4.1 Network architecture convergence

In the conventional WSN networks, there exists a group of wireless sensor nodes to detect data. The WSN gateway can provide the access for the WSN nodes, which WSN gateway just forward the detected data to the backhaul networks servers. And this is just individual integration of WSN and MCN [42], where the gateway is just located in the middle layer to manage the WSN nodes. The integrated network architecture is shown in the **Fig. 3**.

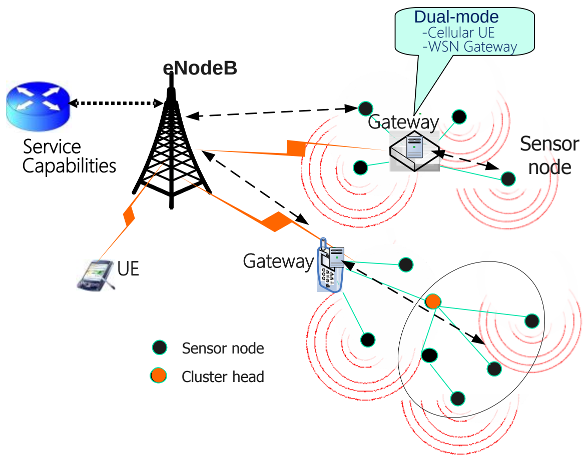

Fig. 3.. Integrated network architecture for MCN and WSN

In the converged networks, the data from WSN nodes can be forwarded to the eNodeB by the gateway directly. In this scenario, the eNodeB of cellular networks can control the WSN nodes, and can optimize the WSN to improve the WSN transmission efficiency. In converged MCN and WSN, the network architecture becomes flat while the conventional network is hierarchical [43]. In the new network convergence approach, the control signaling can be exchanged directly between the MCN and WSN as shown in **Fig. 4**, for instance, the nodes of WSN may have the ability of overhearing the downlink signaling from the eNodeB. As a result, MCN can directly control and manage WSN, which decreases the signaling exchange among sensor node, UE gateway and eNodeB.

In the converged network architecture, the eNodeB can help sensor nodes to choose the optimal access gateway and transmission path. Besides this, more important information of WSNs can be stored in the cellular networks. In this process, extra signaling is introduced to the sensor nodes, which will be large challenges for the whole converged networks. Besides this, extra complexity is introduced to the sensor nodes to equip the downlink receiver, but the complexity will not be large since the device capabilities are much higher nowadays.

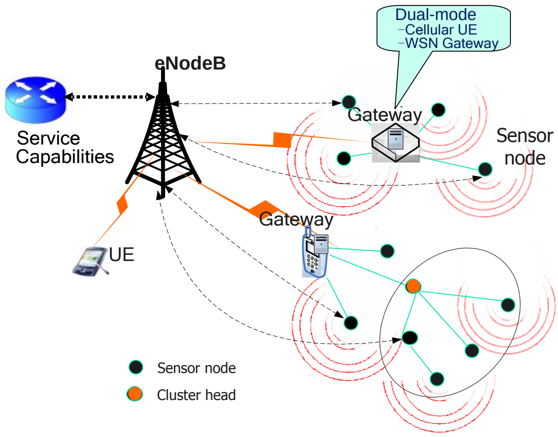

Fig. 4. Converged network architecture for MCN and WSN

4.2 Protocol convergence

In the conventional WSN and MCN integrated networks, the detected data from sensor nodes can be routed to the eNodeB by the gateway, which usually use a data packet switching method between the two protocol stacks [44]. In this case, the switching method is implemented to change data packet format, i.e. packet header, frame control part etc. In the new converged networks, since the network architecture is highly converged, the two network protocol stacks are also converged where the data and signaling are shared between the network stacks [45]. In the integrated network, the data channel between the two protocol stacks is usually implemented in the gateway, as shown in left part of **Fig. 5**. In this case, data channels between the two independent stacks are implemented to exchange information. Since the network architecture and air-interface are highly converged for WSN and MCN in the converged networks, the protocol and control signaling should also be tightly converged for a real convergence of WSN and MCN. In such a converged network, MAC and network layer protocols in the two stacks should be jointly optimized either to achieve some performance gains for WSN or to extend the applications of MCN. As shown in right part of **Fig. 5**, the two protocol stacks are not independent. The data and algorithms are shared between the two stacks.

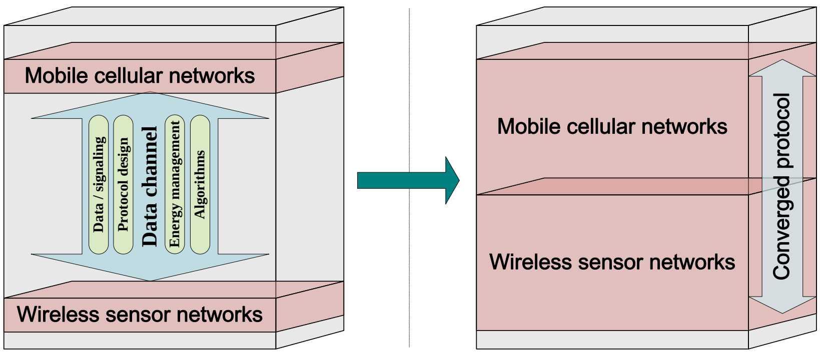

Fig. 5. Converged protocol for MCN and WSN

In MAC layer, the fixed/mobile gateway needs to convey the sufficient/efficient control information to/from the eNodeB for convergence optimization. The gateway needs to request the allocated resources from eNodeB for data transmission. Furthermore, the gateway can map the WSN data and resource requests to MCN frame, and reports to the eNodeB; and then, the eNodeB allocates different WSN channel group to decrease the interference. In addition, the service-type and requirement should be considered to guarantee the transmission QoS.

In network layer, WSN node’s topology changing can be reported to eNodeB periodically. When a mobile gateway enters the coverage area of WSN, it may cause the re-clustering of sensor nodes and network topology changing. How to achieve a performance gain in sensor nodes re-clustering is an essential issue under the help of MCN. With the eNodeB acting as database server, the routing table updating and sharing also needs to be further studied during the MCN and WSN convergence.

4.3 Tradeoff between energy-efficiency and complexity

The WSN may improve the energy efficiency based on the help of MCN and achieve better system performance as discussed in Section III. For instance, the power consumption can be reduced greatly in the gateway re-selection and load balance process for WSN, but the WSN complexity is increased with the additional signaling design for neighbor UE gateways scanning. If the system scenarios are in worst cases, this will maybe cause seriously degraded system performance because of the extra signaling and computing, in terms of throughput, transmission delay and energy consumption [46]. Therefore, there are still several important issues for balancing energy-efficiency and complexity which still require further research [47]. We detail several potential points as follows:

- Software challenge of UE gateway: Both MCN and WSN have different working capacity, resource management requirements. This heterogeneity makes the design of converged system architecture difficult, especially for the UE gateway. The software for UE gateway should have the following function. First, it needs to analyze the collected data, overhear signaling and can abstract the useful information. Second, it should add some improved scheduling algorithm for various WSN services, which will help the network to use channel resource effectively and improve energy efficiency. For instance, in order to achieve the joint resource allocation to guarantee the multi-types services, the UE gateway should construct the resource mapping table in the networks convergence process. Third, it needs to transmit the highest priority information and control signaling to the WSN or MCN with the minimum delay.

- Hardware challenge of UE gateway: Normal UE gateway including WSN and MCN interfaces maybe used in extremely harsh environment. Moreover, the UE gateways maybe move in patrolling mode application. So there are two issues should be considered to address the hardware challenge. One is packaging, and we need to make the UE gateway water-proof, fire-proof. The other is we need to improve the radio module and make it more precise to support the application in moving scenario.

5. Conclusions

MCN and WSN are evolving from heterogeneous to converged in order to satisfy the increasing requirements of M2M communications, where many joint optimized methods and technical challenges still exist. In this survey, we analyze the system applications requirements by using different WSN communication technologies. Further, we propose the MCN-WSN joint optimization for QoS guarantee. And then, we discuss many system technical challenges posed by the unique characteristics of converged MCN and WSN. The open issues in converged MCN and WSN are needed to be researched in order to promote more creative M2M applications in the future.

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