Home M2M Networks: Architectures, Standards, and QoS Improvement

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ABSTRACT

It is envisioned that home networks will shift from current machine-to-human communications to the machine-to-machine paradigm with the rapid penetration of embedded devices in home surroundings. In this article, we first identify the fundamental challenges in home M2M networks. Then we present the architecture of home M2M networks decomposed into three subareas depending on the radio service ranges and potential applications. Finally, we focus on QoS management in home M2M networks, considering the increasing number of multimedia devices and growing visual requirements in a home area. Three standards for multimedia sharing and their QoS architectures are outlined. Cross-layer joint admission and rate control design is reported for QoS-aware multimedia sharing. This proposed strategy is aware of the QoS requirements and resilience of multimedia services. Illustrative results indicate that the joint design is able to intelligently allocate radio bandwidth based on QoS demands in resource-constrained home M2M networks.

INTRODUCTION

Home networks are rapidly developing to include a large diversity of devices/machines/terminals, including mobile phones, personal computers, laptops, TVs, speakers, lights, and electronic appliances. With the dramatic penetration of embedded devices, machine-to-machine (M2M) communications will become a dominant communication paradigm in home networks, which currently concentrate on machine-to-human or human-to-human information production, exchange, and processing. M2M communications is characterized by low power, low cost, and low human intervention [1, 2]. M2M communications is typically composed of a number of networked devices and a gateway. The gateway is responsible for the connection among the devices, and the connection between the M2M communications area and other networks (e.g., the Internet). The M2M network may use an appropriate standardized radio technology based on the requirements of a specific application. From the data management perspective, M2M communications consists of three phases: data collection, data transmission, and data processing. The data collection phase refers to the procedure used to obtain the physical data. The data transmission phase includes the mechanisms to deliver the collected data from the communications area to an external server. The data processing phase is the process of dealing with and analyzing the data, and also provides feedback on how to control the application.

Machines are normally small and inexpensive, which puts several constraints in M2M communications, including energy, computation, storage, and bandwidth. These constraints pose a number of unique challenges in the design of home M2M networks to achieve a highly connected, efficient, and reliable home.

Interference: There is ever more intensive interference with more radio systems in home areas, including unlicensed systems operating in the industrial, scientific, and medical (ISM) frequency band, electronic equipments, and domestic appliances. The performance of M2M communications may be seriously degraded due to such self-existence/ coexistence interference.

Channel dynamics: Wireless channels in M2M communications are notoriously unreliable due to channel fluctuations and noise, which may become even worse due to the complicated construction in an indoor environment.

Resource constraints: The machines may be extremely resource constrained with respect to computation, storage, bandwidth, and power supply. There is always an essential trade-off between energy, reliability, and flexibility due to resource constraints.

Devices heterogeneity: A home network generally comprises a large number of different

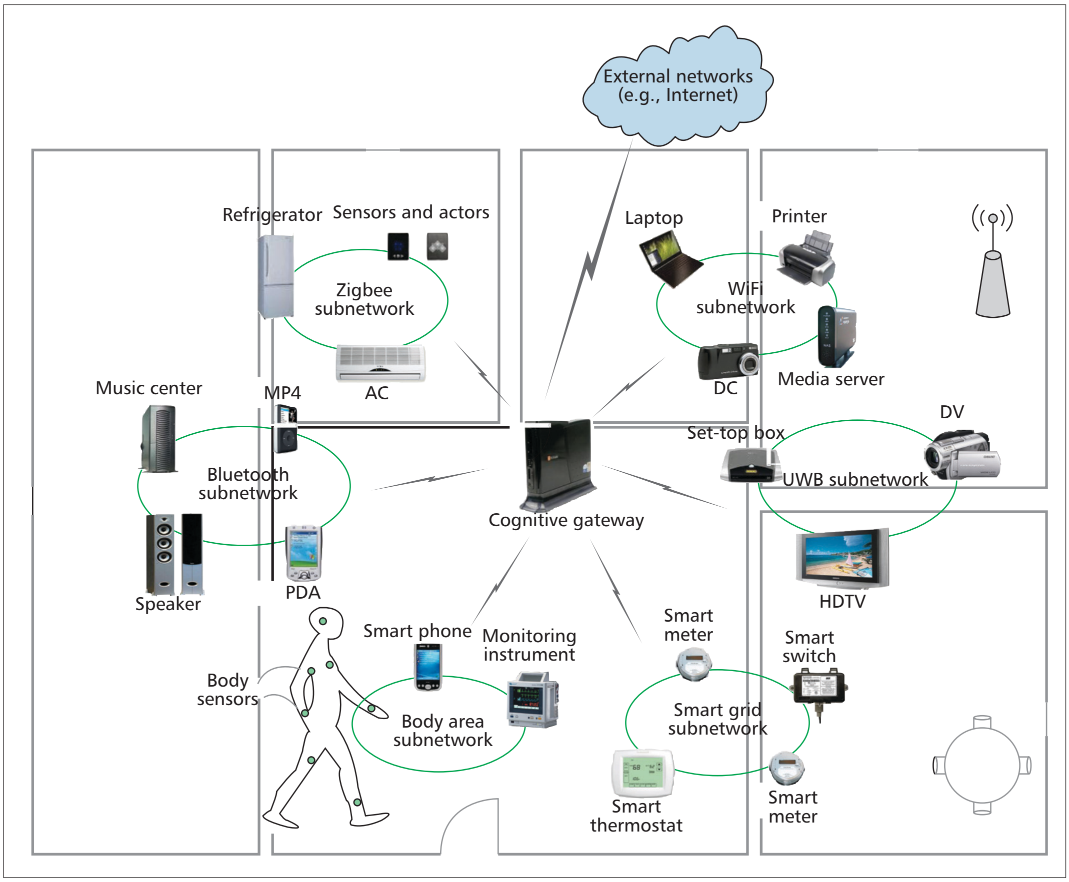

Figure 1. *Proposed home M2M networks architecture.*

M2M enables a diversity of promising services in home surroundings. Some exemplary applications include smart grid, mobile healthcare, home automation, security, appliance monitoring, lighting, and entertainment.

devices as well as distinct services, which may generate dramatically diverse data sources.

Self-organization: Low human intervention is a major property of home M2M communications. This requires self-capability, including self-organization, self-configuration, self-management, and self-healing.

Quality of service (QoS) support: One typical example that requires QoS provision in the home M2M communications is a biomedical sensor network. It is extremely important that life-critical medical data is reliably delivered before being dropped due to the limited memory of most devices.

Security: Home M2M communications are typically required to be inexpensive and preferably unattended, which may expose them to a number of potential attacks. These could be physical attacks, compromise of credentials, configuration attacks, and core network attacks [2].

This article presents key issues and solutions for home M2M networks, including the architecture, potential applications, standards, QoS management, and improvement. We illustrate the network architecture, which is decomposed into three complementary M2M subnetworks: body areas, personal areas, and local areas. The main features and promising applications in each subnetwork are identified. We then focus on QoS management in home M2M networks and present an overview of the standards for media sharing. We also report a prediction-based joint design to improve multimedia QoS in home networks. Illustrative results indicate that the joint design is able to flexibly allocate the limited bandwidth and provide QoS guarantees for multimedia applications in home M2M networks. The conclusion of the article is then presented.

Proposed Architecture for Home M2M Networks

Figure 1 shows a possible architecture for a home M2M network. The home M2M network is essentially a heterogeneous network that has a backbone network and multiple subnetworks. In the backbone network, there is a central machine home gateway (HGW), managing the whole network and connecting the home network to the outside world (e.g., the Internet). The network related functionalities are implemented in the HGW (as shown in Fig. 2), including access control, security management, QoS management, and multimedia conversion. Each subnetwork operates in a self-organized manner and may be designed for a specific application. Each subnetwork has a sub-gateway (SGW) as an endpoint to connect the subnetwork to the HGW as well as the backbone network. It is noteworthy that both the HGW and SGW are logical entities, and their functionalities can be physically implemented in a single device (i.e., cognitive gateway). In the following, we elaborate on M2M communications in body areas, personal areas, and local areas. Key radio technologies in these three subareas are summarized in Table 1, and introduced in more detail later. Furthermore,

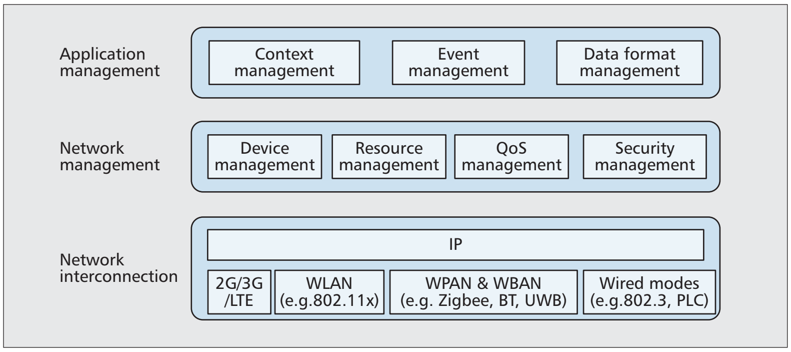

Figure 2. *HGW architecture.*

M2M enables a diversity of promising services in home surroundings. Some exemplary applications include smart grid, mobile healthcare, home automation, security, appliance monitoring, lighting, and entertainment. We identify the potential applications that are supported by each M2M communications scenario.

M2M Communications in Body Areas

M2M communications in body area networks (BANs) primarily provides human-centric services (≤ 2 m). The communications is decomposed into two tiers: intra-BAN communications and inter-BAN communications. Both intra-BAN and inter-BAN communications are typical M2M communications. Intra-BAN refers to the communications among the body sensors, which are strategically deployed on a human body. Inter-BAN refers to the communications between BANs and access points. M2M communications over a body has a number of unique characteristics that substantially differentiate it from traditional wireless ad hoc networks. BANs are usually used in radio- and human-intensive environments. Medical sensors have diverse resource limitations, including power, sensing, communications, and computation. The demand for small medical sensors imposes the use of small batteries, which have a tight constraint on power conservation. Besides, human tissue as the radio propagation medium has drastically different rules from plain space. All these characteristics pose unprecedented challenges in the development of M2M communications in body areas.

Home healthcare is one of the main applications exploiting body areas M2M communications. In this application, there are biomedical sensor networks inside/on/around a person that perform sensing, collection, and transmission of medical vital signs, such as blood pressure, electrocardiogram, oxygen saturation, pulse rate, temperature, and heart rate. The biomedical data are normally either saved in the body area SGW for on-demand remote access or transmitted to remote hospitals/physicians/nurses/communities automatically and periodically. In this sense, medical data are vital shared information among family members and authorized hospitals and healthcare specialists. The home healthcare application can easily be extended to services like e-health, healthy lifestyle, location-based services, and ambient assisted living.

M2M Communications in Personal Areas

M2M communications in personal areas target short-range applications in home surroundings (≤ 10 m). A networked smart meters system is a typical M2M instance offering an energy-efficient and reliable next-generation power grid. A number of short-range communications standards can be employed for personal area M2M communications (e.g., Zigbee [3], Bluetooth, IETF 6LoWPAN, WiFi, and WirelessHART). Zigbee is a wireless networking technology developed by a large consortium of industry players. Zigbee is characterized by low rate, low power, and short-range transmission. Zigbee operates on the IEEE 802.15.4 radio specification. In the physical layer, orthogonal quadrature phase shift keying (O-QPSK) is specified for Zigbee systems that operate in the 2.4 GHz band. There are three device roles in Zigbee: the coordinator, the router, and the end device. For the medium access control (MAC) layer, IEEE 802.15.4 defines two channel access methods: beacon-enabled and beaconless. In the beacon-enabled mode, there is a coordinator that generates and transmits beacons for synchronization. In the beaconless mode, devices employ the carrier sense multiple access with collision avoidance (CSMA/CA) scheme to compete for channel access.

Zigbee recently defined two application profiles for home M2M networks: the home automation public application profile and the smart energy profile. The first one specifies device attributes and commands for applications in a residential environment. The main application areas are lighting, window shades, monitoring, and security. The second one provides an overlaid two-way communication infrastructure to improve efficiency, flexibility, and reliability. Zigbee-enabled smart meters are critical units that efficiently manage demand response, actively respond to different prices, and effectively balance the power consumption load in the power grid. Achieving these objectives is highly dependent on a typical M2M communication scenario, a networked smart meters system, which is characterized by energy efficiency, responsive inquiry, critical performance, and high reliability.

M2M Communications in Local Areas

Local area M2M communications refer to communications between the subnetworks and the external network, or among machines in the home area. The IEEE 802.11 protocol is the de facto standard for wireless local area networks [9]. IEEE 802.11n is a very recent amendment to increase data rates up to 600 Mb/s by adding multiple-input multiple-output (MIMO) to the physical layer and frame aggregation to the MAC layer. 40 MHz channels is another feature in the IEEE 802.11n physical layer to increase the data rate. However, the data rate improvement in the physical layer does not necessary lead to throughput increase due to the MAC layer protocol overhead and packet contention. Thereafter, frame aggregation is incorporated in the MAC layer to combine multiple MAC service data units to reduce the overheads such that the network throughput can be increased [8].

There are a number of novel applications in

Standard	Area	Rate	Energy-constrained	Typical applications	Data Type
Zigbee	Personal area	Low	Yes	Automatic control	Sensors, monitoring, smart grid
Bluetooth	Personal area	Low	Yes	Music sharing	Voice, low-rate data, music
UWB	Personal area	High	No	Video, file sharing	Video, high-rate data, files
802.15.6	Body area	Low	Yes	Healthcare	Biomedical data
WiFi	Local area	High	No	Home thermostats, water metering	VoIP, data, video
Femtocell	Local area	High	No	Cellular phones	VoIP, data, video

Table 1. *Radio technologies for home M2M networks.*

M2M local areas. Several exemplary applications include home thermostats, advanced metering infrastructure, and gas and water metering. WiFi may not be appropriate for wide area networks due to its limited radio coverage; it is, however, a cost-effective option for home area networks and neighborhood area networks. In smart grid applications, the neighborhood area networks will collect energy consumption information from households in a neighborhood and deliver them to a utility company through either open or private wide area networks. Neighborhood area networks typically comprise multiple utility meters, each of which is installed on the outside of a house. Neighborhood area networks can potentially incorporate a multihop mesh topology that can adopt standardized IEEE 802.11s wireless mesh networks. With the increasing number of multimedia devices in a house (e.g., consumer electronics, personal computers, TVs, mobile phones, laptops, and imaginary future ones), there is a greater need for automatic communications among these machines that eventually requires the presence of a home network. In this case, the demand on multimedia sharing among different devices (or family members) is becoming very important. IEEE 802.11e is an amendment in the MAC protocol layer for QoS enhancement and a suitable candidate for supporting multimedia radio transmission in M2M local areas.

M2M Communications Via Cognitive Gateway

Besides the aforementioned wireless network technologies, heterogeneous home M2M networks may also include wireless sensor networks, wide area networks, and/or UWB. Therefore, a flexible service gateway is significant in such a heterogeneous network [4]. To autonomously adapt to different radio technologies, the HGW shall have self-configuration or advanced cognition capability. In this sense, the HGW is able to intelligently interact with the radio surroundings, adaptively connect and change their transmitters' parameters that will connect to the home networks, which in turn will connect to external networks (e.g., the Internet, commercial wide area networks [e.g., Long Term Evolution, LTE] or private networks [utilities]). The HGW performs three tiered tasks: network interconnection, network management, and application management. In terms of network interconnection, the HGW connects to the heterogeneous networks in the M2M home network using IP technology. In the network management IP layer, the HGW deals with network related management (e.g., devices, resources, QoS, and security). In particular:

- Devices and resources management are mainly realized within the Universal Plug-and-Play (UPnP) and Digital Living Network Alliance (DLNA) standards [5, 6].
- QoS management is in charge of admission control, rate control, and other QoS-aware operations.
- Security management protects the home M2M network from possible external attack via trusted access control and networked encryption techniques.

The application management layer is responsible for decomposing an application into a series of M2M communications, figuring out the network settings, and invoking the M2M transmission. In particular:

- Context management acquires and composites any contextual information, and adapts the services to diverse contexts. Before an M2M communication is performed, analysis is needed to identify the context (the application type, network status, device status, etc.).
- Event management triggers an appropriate M2M communications in case of routine or emergent events where the HGW acts as an agent to launch the M2M communication.
- Data format conversion translates the media format in the source node into the format in the destination node when data (e.g., a video file) is shared among heterogeneous devices.

Standards for Device and Resource Sharing in Home M2M Networks

Earlier we presented radio standards in three different M2M communications scenarios. These standards normally specify the physical and MAC layers. In addition to these standardized communications networks, multimedia and its QoS provision are extremely important in home M2M networks since the successful running of

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many applications highly depend on multimedia sharing in the body, personal, or local area. For this, three major standards have been defined for facilitating the application layer multimedia discovering, searching, and sharing in home M2M networks: UPnP [5], DLNA [6], and Intelligent Grouping and Resource Sharing (IGRS) [7].The standard specifications aim to build a world of connected machines and enable a flexible multimedia sharing environment. Automatic communication among these machines is a dispensable functionality in home networks.

UPnP and Its QoS Architecture

UPnP is defined by the UPnP Forum, which is organized by a number of vendors in the fields of electronics, computation, home automation, appliances, computer, mobile services, security, and entertainment. UPnP is essentially a technology in the application layer with the support of TCP/IP protocol stacks in the lower layers. This enables an open and flexible network connectivity and addressing among UPnP devices. There are two logical devices in UPnP: controlled devices (CDs) and control points (CPs). A CD can be a physical or logical network node to provide services. A CP is a controller that can discover and control devices. When a new device is added to a network, it will first obtain its IP address and then advertise its services to CPs via a multicast Simple Service Discovery Protocol (SSDP). When a new CP is added to a network, it shall search for devices of interest in the network. Once a CP discovers a device, it may obtain the device's description file via the device's URL message. The CP keeps listening to the state changes of the CDs. For home multimedia applications, the UPnP audio/video (AV) architecture is the standard for interoperability of multimedia systems among multimedia appliances. This architecture is based on the UPnP processes of discovery, description, control, and eventing, which facilitates a CP coordinating the flows of AV content between the source and sink devices. As a consequence, a consumer can retrieve any shared multimedia by running the CP in her own device and browsing the target media server.

The UPnP QoS architecture specifies service reservation in resource-constrained home M2M networks and simultaneously ensures nondegraded QoS of deployed services. The architecture defines three entities: QoS manager (QM), QoS policy holder (QPH), and QoS device (QD). A QM is the central unit of the QoS system, responsible for managing QoS resources, and discovering and controlling QPH and QD entities. A QPH stores the user's QoS policies, including traffic classes, service priorities, and user types, which are helpful for implementing flow admission control. A QM determines the admission or rejection of a new traffic stream based on a User Importance Number (UIN) ranging from 0 to 255. A QD provides the UPnP interface needed to connect each network device and is responsible for the practical QoS configuration. A QD is responsible for accepting or rejecting a traffic flow, and provides the QM with its own information, including connections, capabilities, and states.

DLNA and Its QoS Architecture

The DLNA standard is essentially an intermediate layer based on the original network framework. In particular, the DLNA Home Networked Device Interoperability Guidelines adopt the UPnP AV architecture for media management and control between networked devices. End users also employ the UPnP mechanism to discover interoperable server devices in the network. An M2M connection is performed automatically without human intervention. The UPnP mechanism is used to search media content. The key of the DLNA protocol is media management. DLNA defines two classes of media formats: compulsory and optional. The DLNA standard defines two main classes of devices: digital media servers (DMSs) and digital media players (DMPs). A DMS is responsible for acquiring, recording, storing, and sharing the media content. A DMP does online searching and plays the media in a home network.

In DLNA, priority-based QoS management is adopted. Four QoS levels are defined: DLNA QoS-3, DLNA QoS-2, DLNA QoS-1, and DLNA QoS-0. Each DLNA QoS level reflects the set of WiFi multimedia (WMM) and differentiated services codepoint (DSCP) priority in wireless networks, and the set of 802.1q and DSCP QoS priority in the Ethernet. Network packets can be marked to different DLNA QoS levels according to their transmission models. DLNA QoS-3 is the highest level, defined for the messages dedicated to connection management and RTCP messages sent from receivers. DLNA QoS-2 is the second highest level, defined for A/V streams, RTSP messages, and RTCP messages sent from transmitters. DLNA QoS-1 is the default level, defined for interaction transports. DLNA QoS-0 is the lowest level, defined for background flows. In the DLNA QoS architecture, no extra devices are defined for QoS management. QoS guarantee is ensured by WMM, 802.1q, and DSCP. Hence, it is easy to implement the QoS architecture, but mandatory guarantees cannot be provided.

IGRS and Its QoS Architecture

IGRS intends to offer seamless resource sharing and service collaboration among devices for communication terminals, computers, and consumer electronics for users at homes, offices, and public areas. IGRS includes three components: core protocols, application profiles, and basic applications. The core protocols define device grouping, and the interaction between clients and services. The application profiles specify the service description. One of the key features of IGRS is taking into account the security issue. IGRS defines two layers of security protocols: the tunnel between devices and the session between users and services. IGRS categorizes the security mechanisms into four levels: identity and messages confirmation mechanism based on the symmetric key cryptosystem; identity authentication, encrypted message transmission, and message authentication based on the public key cryptosystem; and identity authentication, encrypted message transmission, and message signature based on a trusted third party.

IGRS QoS architecture defines three classes of services: IGRS QoS device (QD), IGRS QoS management (QM), and IGRS QoS policy holder (QPH). The IGRS QoS architecture introduces the concept of a QoS segment to deal with the network heterogeneity in a digital home. When a multimedia flow passes through a QoS segment, the QoS related operations are transparent to devices that have no QoS capability. Only the gateway and devices with QoS capability interact with the QM. For instance, for an ultra wideband (UWB) segment, an IGRS UWB QoS architecture is defined with three components: the architecture database, the core, and the protocol. A QoS architecture database stores the mapping rules. A QoS core is responsible for receiving and processing commands from the applications and recording the session status. The QoS core will analyze and retrieve the QoS parameters. The QoS protocol executes the end-to-end parametric QoS protocol and is involved in QoS management.

QoS Improvement in Home M2M Communications

Multimedia sharing is actually an application layer issue. Usually, multimedia sharing contains three main steps: multimedia discovery, transmission, and rendering. Although the existing standards have defined generic QoS architectures for multimedia sharing, the specific QoS management and algorithms are still missing.

Machine Model

A device that contains multimedia resources is called a media device. Media devices and their multimedia resources should be announced to the entire network before the multimedia content is transmitted and presented. A description file of the multimedia resources and media capability are stored inside the media device. Here, media capability represents the media device's ability in managing, controlling, processing, and rendering multimedia resources. For instance, multimedia upload, download, push, pull, and print are all typical media capabilities. Each media device should periodically broadcast its description file in the network to announce its multimedia resources and media capability as well. Multimedia services are broadly classified into two categories: resilient and non-resilient. Resilient services are flexible in QoS requirements, while non-resilient services have hard QoS requirements. Video and data communications are typical resilient services, which are usually tolerant in degraded QoS at some extent. Accordingly, there are two classes of media devices: those capable of processing resilient media, and those only capable of processing non-resilient media.

A Cross-Layer Joint Design

In this section, we propose a joint rate and admission control (JARC) scheme for QoS provision in wireless home networks. The key feature of JARC is that it supports QoS simultaneously at the application layer and the network layer. The design of JARC:

- Exploits the heterogeneous nature of digital home appliances and the flexibility of scalable multimedia processing, ensuring QoS satisfaction at the application layer
- Accurately predicts the QoS parameters (i.e., the delay) with respect to the bandwidth configuration of multimedia sessions and is able to provide parameterized QoS guarantee at the MAC layer

Figure 3 shows the proposed QoS management framework. There are two main components: the rate control entity (RCE) and admission control entity (ACE). The RCE is responsible for user-oriented bandwidth configuration. The ACE controls the number of sessions in the network to guarantee the QoS of current multimedia services at the network level. An efficient queueing analysis unit, capable of accurately predicting the QoS parameters for a given bandwidth configuration of multimedia sessions, is integrated in ACE. The interaction of RCE and ACE is crucial for ensuring the coherence of the QoS requirements at the application and MAC layers.

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QoS Management

Initialization — The admission and rate control procedure is launched by an initializing media device, which triggers multimedia sharing in the home network. The initializing media device sends a request message to the QoS manager, requesting admission to set up a new multimedia session. The request message contains the basic information of the media transmitter and receiver (e.g., IP address and device type). Upon receiving the request message, the QoS manager invokes the RCE and sends out inquiry messages to the media devices for full information of the session property and capability of the devices, such as screen size, processing capability, and acceptable bandwidth. The information exchange between the QoS manager and the media devices can be accomplished within the UPnP QoS framework. In this case, JARC is compatible with many existing home networking protocols that stem from UPnP.

QoS Control — After obtaining feedback, the RCE will first examine whether the session property matches the device capability. The examination is necessary to avoid a situation where the initializing media device has incomplete knowledge of the capability of the media receiver. For instance, in a typical third-party multimedia sharing mode, a PDA acts as the central controller of the home network. The PDA may try to push a photograph from a digital camera (the media transmitter) to a PC (the media receiver) for printing. However, the PC may not be connected to a printer and cannot fulfill the printing task. Thereafter, if the RCE finds that the media receiver is incapable of providing the required multimedia service, it will notify the ACE to directly deny the new session. If the device capability matches the multimedia session, the RCE will check the scalability of the multimedia source.

For a non-scalable source, the RCE will report the QoS requirement to the ACE, which shall decide whether the session is acceptable or not based on the result of the queueing analysis unit. For a scalable source, there are multiple optional rates. After obtaining this scalability

Session number	1	2	3	4	5
Traffic type	Audio 1	Audio 2	Video 1	Video 2	Data
Source model	IDP	IDP	4IRP	4IRP	4IPP
Packet size (bytes)	192	192B	600B	600B	1400B
Mean rate	64 kb/s	64 kb/s	4.2 Mb/s	4.2 Mb/s	2.7 Mb/s
Peak rate	184 kb/s	184 kb/s	4.7 Mb/s	4.7 Mb/s	3.9 Mb/s
Priority level	3	3	2	2	0

Table 2. *Simulation parameters for five multimedia sessions.*

information, the RCE should perform bandwidth allocation to optimize the combination of the bandwidths of the existing sessions and new session. The RCE passes to the ACE the bandwidth configuration file, which could be treated as the desire for QoS provision at the application layer. After performing a queueing analysis, the admission control entity replies to the RCE with an instruction that indicates whether or not the desired QoS is achievable at the MAC layer. If a positive reply is received, the new session is admitted into the network; otherwise, the RCE has to perform bandwidth reconfiguration. A new round of interactions of the RCE and ACE takes place. If all the bandwidth configuration files are not allowed, the new session is rejected.

Bandwidth Allocation Scheme — The bandwidth allocation unit is responsible for acquiring the knowledge of device capability (both the transmitter's and the receiver's) and the new session property. Based on this knowledge, the bandwidth allocation unit will figure out the optional rates of the new session. Suppose there are totally N sessions in the network (let the new session be the Nth one). For the nth session, there are M_n acceptable rates. Let r_n^m ($1 \le n \le N$, $1 \le m \le M_n$, $r_n^1 \le \cdots \le r_n^m \le \cdots \le r_n^{M_n}$) denote the m-th acceptable rate of the n-th session, and Φ denote the set of all optional bandwidth configurations. We have $\Phi = \cup_{m1=1}^{M1} \cdots \cup_{mN=1}^{MN} (r_1^{m1}, \cdots, r_N^{mN})$ where $(r_1^{m1}, \cdots, r_N^{mN})$ represents an acceptable bandwidth configuration, denoted by $\phi_{m1,\ldots,mN}$.

Bandwidth allocation is performed to maximize utilization and maintain fairness. Suppose that the current rate of the nth session is r_n^{Kn}. To decide the rate of the new session (the Nth session), we start from the highest acceptable rate (i.e., r_N^{MN}) and the desirable bandwidth configuration is $\phi_{K1,\ldots,KN-1,MN}$. This bandwidth configuration will be passed to the ACE. If the ACE denies the configuration, bandwidth reconfiguration is needed. To prevent the ongoing multimedia services from QoS degradation, the next option is to choose the configuration $\phi_{K1,\ldots,KN-1,MN-1}$ by lowering the QoS of the new session by one rate level. Following this rule, the reconfiguration may be repeated, if necessary, until the configuration $\phi_{K1,\ldots,KN-1,1}$ is rejected. At this point, no lower rate for the new session is available, so we degrade the QoS of the current sessions. For the sake of fairness, it is reasonable to choose the session with the highest rate and decrease its bandwidth by one level. A configuration from the highest rate of the new session is restarted. The process of bandwidth configuration may be repeated unless even configuration $\phi_{1,\ldots,1,1}$ is not allowed. In this situation, the new session is rejected.

Illustrative Results

In this section, we evaluate the proposed joint admission and rate control scheme. In the simulation scenario, media devices are connected in a wireless manner for multimedia sharing in a home network. The JARC QoS manager is implemented in the wireless home gateway, which is responsible for making admission and rate control

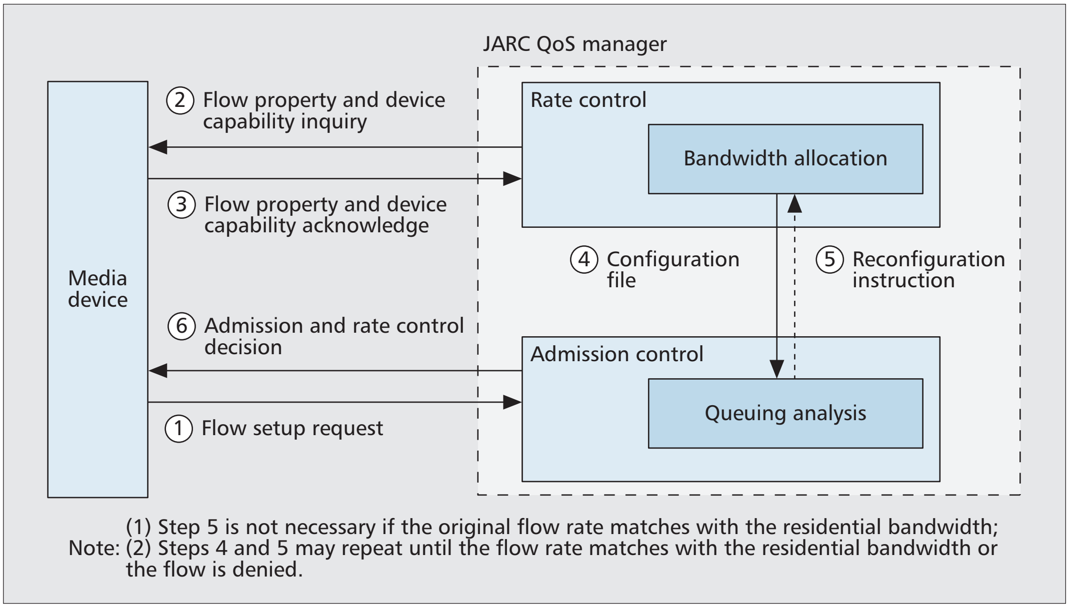

Figure 3. *A proposed joint design framework.*

decisions. The simulation is carried out in the OMNeT++ simulator. Table 2 shows five multimedia sessions in a home network. We use the traffic models in [10]. In particular, the audio sessions are generated by the Interrupted Deterministic Process (IDP) model, the video sessions are generated by the Interrupted Renewal Process (IRP) model, and the data session is generated by the Interrupted Poisson Process (IPP) model. Session one is an audio service for music sharingfrom MP3 to a WiFi speaker. Session two is the second audio (voice over IP, VoIP) service from a notebook to a WiFi headset. Session three is a video service for TV program watching from a set-top box (STB) to a digital TV (DTV). Session four is the second video service, movie sharing from a media server to a laptop. Session five is a data service for FTP file sharing from a PC to a networked HDD. The simulation runs for 600 s. In the first 300 s there are three sessions, Audio-1, Video-1, and the data session running at full rates. After that, Audio-2 and Video-2 sessions are triggered. The home gateway will make intelligent decisions on the acceptance or rejection of Audio-2 and Video-2 sessions.

Figure 4 shows the performance metric delay in the home network with/without the joint cross-layer design. "Audio without joint design" shows the delay of Audio-1 without the cross-layer joint design. The delay changes from 4 ms to 18 ms at the instant when the new audio and video sessions join the network. "Video without joint design" shows the delay of Video-1 without the cross-layer joint design. The delay changes from 4 ms to 20 ms at the moment the new audio and video sessions join the network. Figure 4 also shows that, with our proposed scheme, the delays of Audio-1 and Video-1 remain unchanged although new audio and video sessions are admitted into the network. Hence, the presence of an admission control strategy could protect the QoS of an existing video session, but has to deny a new video session. When the proposed JARC is applied, the new video session can be accepted into the network. In addition, the delay of the video sessions remains at a low level. The compensation is to moderately degrade the source rate of the video sessions.

Figure 5 shows the packet loss rate performance metric in the home network with/without the joint cross-layer design. "Video without joint design" indicates that Video-1 suffers severe packet loss in the last 300 s. In addition, the packet loss rate of Audio-1 in the last 300 s is clearly higher than that in the first 300 s. A large portion of video packets and a small portion of audio packets are lost in the last 300 s. This observation demonstrates that the packet loss rate of the audio and video sessions may not be guaranteed if there are no appropriate admission and rate control strategies. With our proposed JARC mechanism, the packet loss rate of Audio-1 remains low in the last 300 s. The packet loss rate of Video-1 is lower than that in the first 300 s. In fact, the number of lost packets of two video sessions in the last 300 s almost equals that of Video-1 in the first 300 s. By moderately reducing the source rate of video sessions, JARC is able to flexibly handle the packet loss rate of real-time sessions.

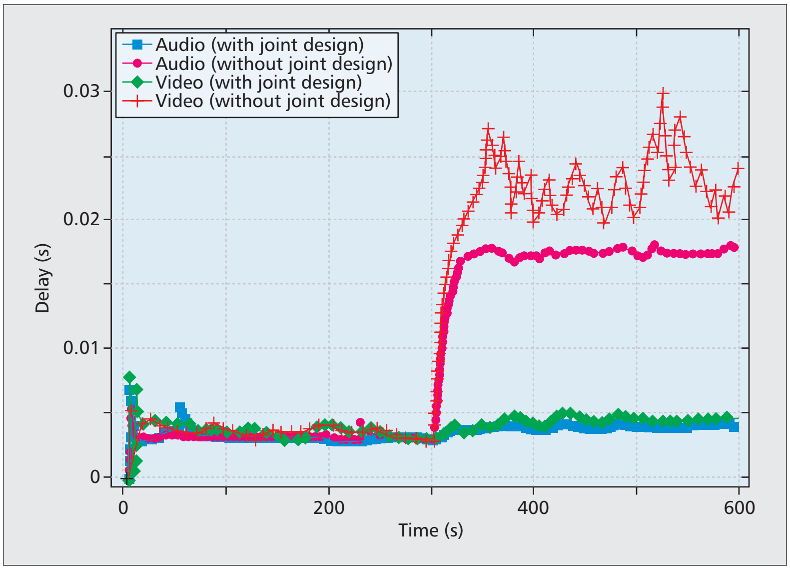

Figure 4. *Delay in the scheme with/without joint design.*

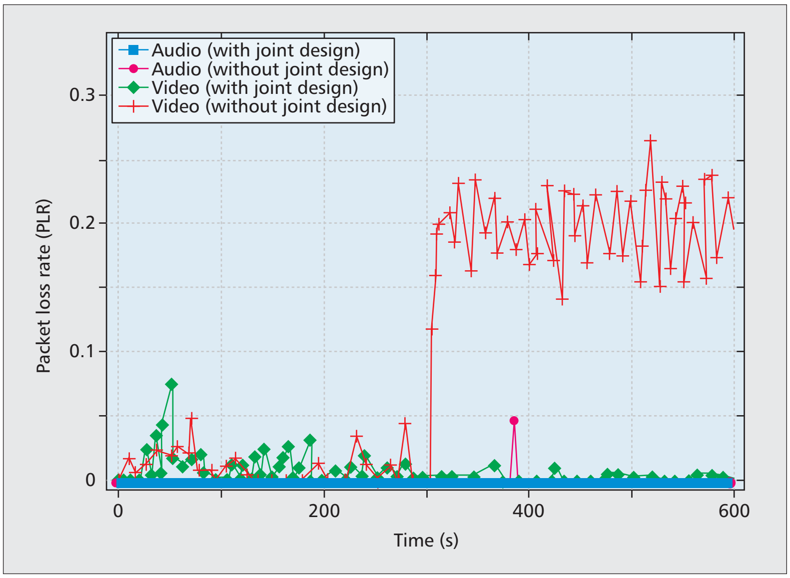

Figure 5. *Packet loss rate in the scheme with/without joint design.*

Conclusions

In this article, we first identify the fundamental challenges in home M2M networks. Then we present the architecture of home M2M networks decomposed into three subareas depending on the type of applications and their service ranges. The standardized radio technologies and their potential applications in these three subareas are also discussed. Then, we focused on QoS management in home M2M networks, considering the increasing visual and multimedia requirements and rapid penetration of multimedia devices in home surroundings. Three multimedia sharing standards and their QoS architectures are outlined. A cross-layer joint admission and rate control design is proposed for QoS-aware multimedia sharing. The design is able to analyze and predict QoS performance, and adaptively allocate appropriate wireless bandwidth to accommodate more multimedia sessions without

A cross-layer joint admission control and rate control design is proposed for QoS-aware multimedia sharing. The design is able to analyze and predict the QoS performance, and adaptively allocate appropriate wireless bandwidth to accommodate more multimedia sessions without QoS degradation.

QoS degradation. Illustrative results indicate that the joint design is able to intelligently allocate resources based on QoS demands in resource-constrained home M2M networks.

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