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Modelling the Integrated QoS for Wireless Sensor Networks with Heterogeneous Data Traffic

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ABSTRACT

The future of Internet of Things (IoT) is envisaged to consist of a high amount of wireless resource-constrained devices connected to the Internet. Moreover, a lot of novel real-world services offered by IoT devices are realized by wireless sensor networks (WSNs). Integrating WSN to the Internet has therefore brought forward the requirements of an end-to-end quality of service (QoS) guarantee. In this paper, the QoS requirements for the WSN-Internet integration are investigated by first distinguishing the Internet QoS from the WSN QoS. Next, this study emphasizes on WSN applications that involve traffic with different levels of importance, thus the way real-time traffic and delay-tolerant traffic are handled to guarantee QoS in the network is studied. Additionally, an overview of the integration strategies is given, and the delay-tolerant network (DTN) gateway, being one of the desirable approaches for integrating WSNs to the Internet, is discussed. Next, the implementation of the service model is presented, by considering both traffic prioritization and service differentiation. Based on the simulation results in OPNET Modeler, it is observed that real-time traffic achieve low bound delay while delay-tolerant traffic experience a lower packet dropped, hence indicating that the needs of real-time and delay-tolerant traffic can be better met by treating both packet types differently. Furthermore, a vehicular network is used as an example case to describe the applicability of the framework in a real IoT application environment, followed by a discussion on the future work of this research.

TYPE OF PAPER AND KEYWORDS

Regular research paper: *wireless sensor networks, Internet of Things, quality of service, service differentiation*

1 INTRODUCTION

Wireless sensor networks (WSNs) consist of tiny, low-power wireless sensors that have sensing, computation and communication capabilities. WSNs have been deployed in diverse applications such as health monitoring, environmental observation, structural monitoring, habitat monitoring, energy management, and disaster management. Traditionally, WSNs are built as a standalone network. However, with the emergence of many important WSN applications, the efforts to integrate WSNs with the Internet have been around for more than a decade. The intended integration would provide seamless access to the unattended devices, hence offering high-resolution knowledge about the sensed phenomena. In addition, to provide a more comprehensive set of services for their users, efforts have been given to interconnect isolated WSNs, which are physically located in different locations in order to form one virtual sensor network.

Part of the major challenges in integrating WSNs to the Internet is to provide reliable and efficient connection between both networks. WSNs should interwork with the Internet, in order to build an end-to-end application system for their users. To date, efforts are mostly given to investigating the possible integration approach, the practical implication such as security, and the sensor level protocol [1-4]. While the complete integration of WSNs and the Internet still remains an open issue, quality of service (QoS) must be taken into account in order to provide reliable network performance for the integration. Indeed, there is a glaring lack of studies in the area of QoS support for WSN-Internet integration. In this perspective, it is imperative to identify QoS requirements of the network, in order to define a mechanism for the QoS provisioning for the integration.

The motivation behind this study is twofold; firstly, traffic in WSNs represent two kinds of co-existing data packets: those with real-time constraints and those with reliability-constraints [5]. These packets have different QoS requirements. Thus, by treating these packets differently, the needs of both packet types can be better met. Secondly, QoS requirements generated by both WSN and the Internet are very different [6], due to the significant differences between the two networks. Hence, the interoperability between WSN and the Internet that employs different QoS mechanism may also influence the network performance. Putting this into consideration, a cross-domain QoS that provides some kind of mapping mechanism between both varying WSN QoS and the Internet QoS should be made available. A mechanism for an end-to-end service differentiation will be able to preserve the QoS implemented between different network layers.

In this paper, the potential of differentiated service-based QoS in handling different traffic WSNs is investigated. In addition, delay-tolerant network (DTN) [7] approach is considered in integrating WSNs to the Internet, in order to provide the mechanism for cross-domain QoS mapping for the integration. We present a QoS framework for the integration and investigate the network performance pertaining to the mixture of traffic within the network.

The remainder of this paper is organized as follows: In Section 2 the QoS approach in both Internet and the WSN is investigated, along with a discussion on the QoS requirements concerning different levels of traffic importance. In addition, an overview of DTN-gateway solution as being one of the common approaches for WSN-Internet integration is given. In Section 3, a framework of differentiated service is presented, along with a QoS mapping model for a delay-tolerant WSN interconnected to the Internet. Next, in Section 4, an implementation of the service differentiation QoS solution through network modelling on OPNET is presented. This is followed by a discussion on the simulation results in Section 5, along with a description of an example case to map its application to the associated design and performance parameters of the simulation. Finally, Section 6 describes our future work, followed by concluding remarks in Section 7.

2 WSN-Internet Integration and Quality of Service

In this section, the Internet QoS support and the WSN QoS requirements are first distinguished. Then, the efforts in addressing different QoS requirements by different packet types within WSNs, from existing literatures are discussed. This is followed by an overview of the approaches for integrating WSN with the Internet. This section concludes with a discussion on an envisioned QoS framework for the integration.

2.1 Internet QoS and WSN QoS

RFC 2368 [8] definition on Internet QoS-based routing characterizes QoS as a set of service requirements to be met when transporting a packet stream from the source to its destination. QoS refers to an assurance by the Internet to provide a set of measureable services attributes to the end-to-end users in terms of delay, jitter, available bandwidth and packet loss. Therefore, the QoS efforts have been pursued towards end-to-end support using a large number of mechanism and algorithm in different protocol layers while maximizing bandwidth utilization.

QoS support in the Internet can generally be obtained by means of over-provisioning of resources and/or traffic engineering. While traffic bursts in the network could cause congestion, the default approach of over-provisioning which treats users at the same service class may not always provide an acceptable solution. As a QoS-enabled network allows for handling different traffic streams in different ways, this necessitates traffic engineering approach which classifies users into classes with different priority.

IntServ model and DiffServ model [9, 10] are the typical QoS models employed in the Internet, which employs reservation-based and reservation-less approach, respectively. While network resources are assigned according to an application’s QoS request and subject to bandwidth management policy in IntServ, QoS in DiffServ is achieved via some strategies such as admission control, traffic classes, policy managers and queuing mechanism.

Traditional QoS such as those employed in the Internet mainly result from the rising popularity of end-to-end bandwidth–hungry multimedia applications. On the contrary, the metrics concerned such as available bandwidth and delays may not be pertinent in most WSNs environment. In other words, the QoS solutions such as IntServ and DiffServ developed for traditional networks cannot be easily ported in WSN due to severe resource constraints in sensor nodes, large-scale and random deployment of sensor nodes, and application specific and data-centric communication protocols in WSNs. Consequently, in the recent years, considerable efforts have been given in defining WSN QoS, which include QoS strategies through MAC protocols, routing protocols, data processing strategies, middleware and cross-layer designs.

Since WSNs are envisioned to be employed in diverse applications, many researchers suggest that different WSN application imposes different QoS requirements. The two perspectives of QoS in WSNs described in [6], namely *application-specific QoS* and *network QoS*, represent the two major categories of the existing research for WSN QoS.

In terms of application-specific QoS, the QoS parameters are chosen based on the way an application imposes specific requirements on sensor deployments, on the number of active sensors, or on the measurement precision of the sensors. These attributes are all related to the quality of applications. The following QoS parameters may be considered to achieve the quality of applications: coverage, exposure, measurement errors, and number of active sensors. The QoS support in this approach is not directly related to the QoS support from the underlying network.

On the other hand, from the perspective of network QoS, the QoS parameters are chosen based on the way data is delivered to the sink and corresponding requirements. The main objective is to ensure that the communication network can deliver the QoS-constraint sensor data while efficiently utilizing network resources. The QoS parameters from this perspective include latency, delay and packet loss, which are similar to traditional end-to-end QoS metrics.

2.2 Service Differentiation for Real-time QoS and Delay-tolerant QoS in WSN

In a real-time system or delay intolerant WSN, QoS guarantees can be categorized into two classes: hard real-time (HRT) and soft real-time (SRT). As stated in [11], "*In HRT system, deterministic end-to-end delay bound should be supported. The arrival of a message after its deadline is considered as failure of the system. While in SRT system, a probabilistic guarantee is required, and some lateness is tolerable*". Taking into account these heterogeneous QoS requirements, service differentiation has consequently become a common approach to achieve the QoS for real-time WSN applications. However, as mentioned in Section 2.1, typical QoS solutions such as DiffServ employed in traditional networks cannot be easily ported in WSN. Hence, starting with one of the earliest work in differentiated service-based QoS in [12], subsequent efforts in this area of research have demonstrated this approach of QoS provisioning, specially designed to suit resource constraint WSN [13-20]. While the proposed mechanisms involve different aspects of service differentiation, namely, QoS-aware routing, priority based scheduling, probabilistic QoS guarantee and MAC protocol, the works are based on the common nature of WSN – the network is comprised of different data types, hence demand different levels of QoS from the network. However, like many other real-time QoS solutions in WSNs [11], the differentiated service strategy gives the primary attention to delay-sensitive [21] packets – the aim is mainly to cater for real-time packets that need to arrive at the sink in a required time frame, ensuring low latency and low delay.

In contrast to real-time systems, a delay-tolerant WSN [22] is characterized by long-delay and intermittent connectivity. The main feature of the QoS provisions in delay-tolerant applications, for example, in a sparse mobile sensor networks such as vehicular networks [23] and wildlife tracking networks [24], is reliable message delivery. In addition, DTN concept [7] which makes use of store-and-forward techniques within the network, is employed to compensate the unstable connectivity. Research activities in this area are mainly on routing protocols [25-28] geared at minimizing the delivery delay.

On the other hand, many sensor network applications have two kinds of co-existing data packets: those that must be sent to the base station quickly and those that must be sent reliably. Therefore, the QoS requirement can be classified into two domains: *timeliness* and *reliability* [5, 17]. Within the timeliness domain, different types of data may have different deadlines – some may have shorter deadline while some may be longer. Similarly, the sensory data may also have diverse reliability requirements – some data can tolerate a certain percentage of loss during transmission whereas others may need to be delivered to the destination without any loss.

The work in [28, 29] are geared to address both timeliness and reliability QoS requirements. In [28], to route packets through a WSN with mixed priorities traffic, the real-time packets are allocated more bandwidth, whereas the delay-tolerant data with reliability-constraint are allocated more storage in the buffer within sensor nodes. The work is designed to represent a farm consisting animal farms which are tagged with sensor nodes. In this work, two types of packets are generated – one for the environment data of the surrounding environments and the other for the health condition of the herds. The former is considered as the delay-tolerant data while the latter must be sent quickly, especially during emergencies, hence is assumed as real-time data. Another example of WSN application with different data types is a typical intruder detection system [30], in which data are sent to sink node periodically. Typically, when an important event occurs in the system, the sensor node that detected the event should send the alarm message to the sink. This alarm messages could be in the form of multiple packets containing information such as the time and place of the intrusion. Usually this kind of high priority is bursty. In other words, high priority traffic is generated only within a short period of time while low priority traffic usually exist in the network and produce thousands of packets generated periodically.

While the differentiated service in the aforementioned works operate at the sensor nodes level, a particular attention is required for enabling the QoS in the domain of IoT [31]. In this perspective, it is an interesting challenge to define a QoS mechanism which involves the components beyond the scope of sensors and WSN sink levels. Thus, in the next section, an overview of the salient features of WSN-Internet integration is given, in order to provide an insight of the integrated QoS components facilitating seamless interaction between both networks.

2.3 Integration Approaches

Figure 1 illustrates the architecture of WSNs integrated to the Internet. The network architecture comprises a 3-level network. The bottom level represents multiple isolated WSNs, whereas the intermediate and upper levels consist of the Internet and user terminals, respectively.

There are several strategies to accomplish the integration between WSN and the Internet. The most common integration approach is by employing a gateway-based solution [32, 33]. In this strategy, the sink or the base-station of the WSN serves directly as an interface between the sensor network and the Internet. The sink operates as a gateway, i.e. a proxy that performs translation of lower layer protocols from the WSN to the Internet, and vice versa.

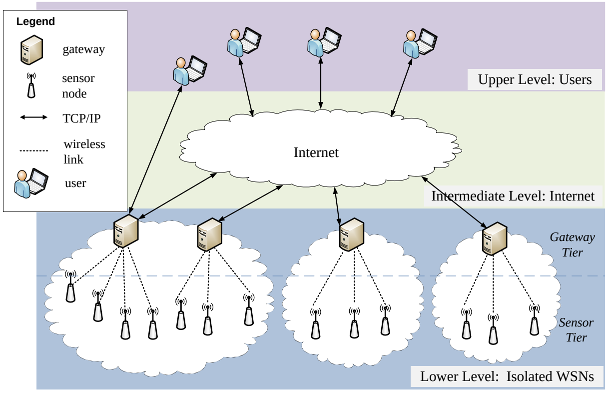


Figure 1: Reference Architecture

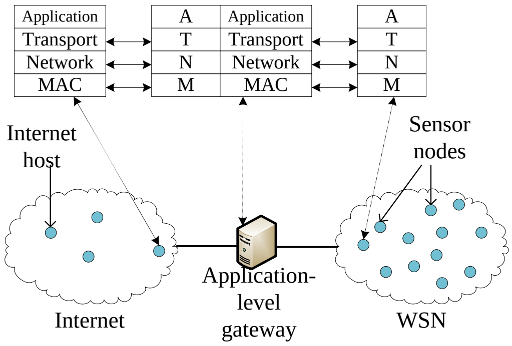
There are variations to this solution, specifically by having different gateway capabilities, namely application-level gateway solution and delay-tolerant network (DTN) gateway [7] solution. Another approach is through a direct integration of IP stack on the smart sensor level, which makes it possible to connect WSNs and the Internet without requiring proxies or gateways. In this approach, the sink or the base-station acts as a router, mainly to forward the packets from and to sensor nodes. An overview of IP-based integration for the recent years is given in [34].

Figure 2 shows the difference between the application-level gateway solution and the DTN-gateway solution. A DTN gateway adopts a store-and-forward message switching, i.e. a packet is stored until the channel is available for sending it to the next hop. This approach is used mainly to address several network issues in challenged environments such as long and variable delay, asymmetric data rates and high error rates.

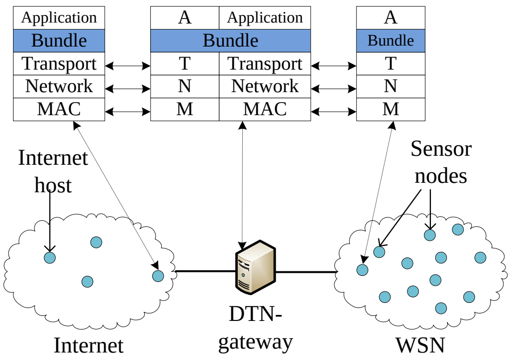
The messages, called bundles, that are transmitted contain both user data and relevant meta-data. The bundle layer works as an application layer on top of TCP/IP protocol stack. In DTN architecture, when the DTN-gateway receives a packet from the Internet, it transforms the lower layer messages of the bundle layer into those of WSNs, and then delivers the packet to WSNs.

If the link of WSNs is broken due to high error rate in the wireless link, the packet is not transmitted, however, it will instead be stored at the bundle layer for future forwarding. Hence, in many ways, DTN gateways operate similarly to Internet routers, but are adapted to use in high-delay and disconnected environments.

In certain circumstances, disparate WSNs need to be integrated into one virtual sensor networks over wired/wireless networks, in order to provide comprehensive services to users [35]. In other words, the actual condition of a phenomenon may be



(a) Application-level gateway solution



(b) DTN-gateway solution

Figure 2: Gateway-based Integration

determined through a combination of sensory data from nodes that may be constituents of different WSNs. Since DTN deploys an additional bundle layer in both TCP/IP network and non-TCP/IP network protocol stacks, it becomes a desirable approach in integrating different WSNs into one virtual network. Indeed, a fully DTN-enabled WSN would easily be extended to a TCP/IP network, simply by connecting one or more of the DTN-gateways to the TCP/IP network [1].

2.4 QoS Over Heterogeneous Networks

As the QoS employed in WSN differs greatly from that of the Internet, interconnectivity issues between the two domains is inevitable. Hence, the QoS provisioning become increasingly important as the network is made up of heterogeneous components. The challenge in generic heterogeneous networks is to offer an end-to-end QoS guarantee in a transparent manner.

A framework to address the cross-domain QoS problem is proposed in [36, 37]. The proposed framework is designed to facilitate a seamless QoS interaction between an ad-hoc networks and an access network, i.e., the Internet. While the QoS solutions on the ad-hoc network are defined to address specific problems such as mobility and fading of wireless channel, the common QoS solutions (such as DiffServ), on the access network are designed to address issues on fixed structure networks. Thus, a framework which runs on a QoS gateway is proposed to solve the interconnectivity issues between the two different domains.

The overall problem of QoS interworking may be structured into two different actions; vertical QoS mapping and horizontal QoS mapping [38]. The concept of vertical QoS mapping [39] is based on the idea that a telecommunication network is composed of functional layers and that each single layer must have a role for an end-to-end QoS provisions. The overall result depends on the QoS achieved at each layer of the network and it is based on the functions performed at the layer interfaces. On the other hand, the concept of horizontal QoS mapping refers to the need to transfer QoS requirements among network portions that implement their own technologies and protocols.

2.5 Envisioned QoS Framework

The task of connecting WSNs to the Internet brings with it several challenges, including the QoS provisioning for the integration. Moreover, being in a unique position of having the full knowledge and control over both the WSN and the Internet, the gateway plays a vital role in guaranteeing QoS for the integration. Hence, in a gateway-based integration network, the QoS implementation is commonly provided on the gateway side of WSN.

In regards to the heterogeneous QoS requirements within a WSN, while it is typical that timeliness is of greater concern than reliability [40], we argue that both QoS domains are equally vital. Hence, the QoS requirements of different traffic types need to be carefully considered in the traffic management running on top of the WSN gateway. On the other hand, in regards of distinguishable WSN QoS and Internet QoS, a mechanism to communicate the varying QoS should be made available. Hence, a QoS mapping framework will facilitate a seamless QoS interaction [36, 37] between both networks built over heterogeneous components. Therefore, both the service differentiation and QoS mapping in the gateway will be the major components to form a complete QoS provisions in integrating a WSN to the Internet.

3 QoS Framework

This section presents a QoS framework for integrating a WSN with mixed traffic requirements with the Internet. The objective of the QoS scheme is to achieve an end-to-end service differentiation that preserves the QoS mechanism between both networks using QoS gateway [37, 41]. Hence, a framework featuring the following components is proposed:

i) A QoS model that explicitly deals with different requirements for different types of data by applying a prioritization scheme among WSN traffic

ii) A QoS model that utilize DTN architecture to realize the communication between isolated WSNs, in order to have seamless QoS interactions between WSN and the Internet

3.1 System Components

The system has two parts: Firstly, a model for differentiated service support for WSN applications connected to the Internet is defined, which represent the *Supple Service Model* discussed in [42]. This service model is discussed in detail in Section 3.3. Secondly, an integration architecture deploying DTN concept is proposed, in order to achieve QoS mapping [38] between the WSN and the Internet.

3.1.1 Differentiated Service

This section presents the prioritization scheme among network traffic, in order to apply service differentiation on the gateway side. The model can support two major types of traffic classes, namely, Expedited Forwarding (EF) class, which is assigned to real-time traffic, and Assured Forwarding (AF) class, which is assigned to delay-tolerant traffic. EF traffic is associated with certain deadlines, while AF traffic has reliability-constraint associated to a certain percentage of loss. In addition, each real-time and delay-tolerant traffic classes can be further divided into different levels of importance corresponding to their reliability requirements.

For example, four types of traffic classes can be specified, namely:

(i) EF class (real-time traffic)
(ii) AF1 (delay-tolerant traffic, high priority)
(iii) AF2 (delay-tolerant traffic, medium priority)
(iv) AF3 (delay-tolerant traffic, low priority)

AF1 must be delivered without any loss, while AF2 and AF3 can only tolerate a certain percentage of loss.

The queuing model in the gateway is shown in Figure 3. The main approach is to allocate optimal resources to packets with different QoS requirements, i.e., more bandwidth to the real-time packets, and more storage for delay-tolerant packets with reliability-constraint. Hence, the real-time traffic are buffered in a separate queue in the gateway buffer, before being forwarded to users through the Internet.

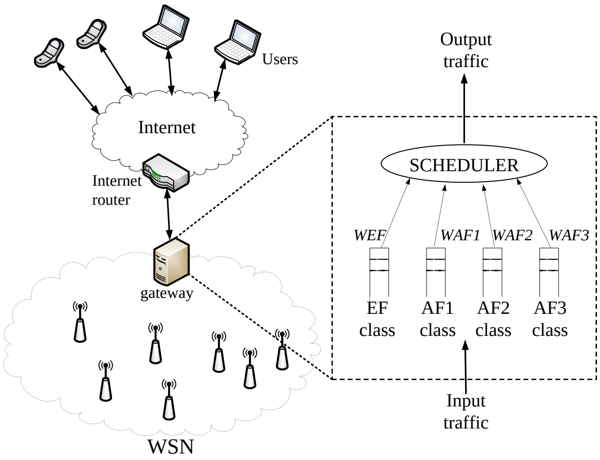


Figure 3: Priority scheduling on the gateway

3.1.2 Buffer Eviction Policy

On top of the priority based service differentiation, a prioritized eviction policy [28] is defined, to be integrated on the WSN gateway device. The priorities in terms of buffer eviction are assigned in the following order, from highest to the lowest:

(i) New AF packets
(ii) Old AF packets
(iii) New EF packets
(iv) Old EF packets
(v) Old EF and AF packets that have been relayed from the gateway

Hence, AF packets always have higher priority than the EF packets in the buffer, because EF packets have no reliability-constraints. Therefore, as packets continue to be stored in the buffer, the eviction policy will introduce another level of service differentiation in terms of allocating longer storage duration for the reliability-constraint traffic.

3.2 QoS Mapping with DTN Gateway

Another major component of the integrated QoS framework is the implementation of DTN-gateway based approach, in order to achieve the QoS mapping between WSN and the Internet. DTN has been advocated for integrating heterogeneous networks through the Internet [41].

As discussed in section 2.4, the overall issue of QoS interworking may be addressed using QoS mapping. In order to address the end-to-end QoS, a QoS gateway should be located in between both networks, and link the QoS solution employed in the WSN with the QoS solution employed by the Internet [37].

Table 1: QoS management functions

Name	Intervention Time
Flow/Traffic class identification	Packet time
Traffic shaping	Packet time
Scheduling	Packet time
Flow control	Round trip time
Call Admission Control	Connection time
QoS routing	Connection time
Resource allocation and reservation	Connection time (long term)

The implementation of vertical and horizontal mappings requires the use of QoS management function, as shown in Table 1. The table consists of a list of necessary QoS management functions along with an indication of the time interval at which they applied [41]. Packet time, round trip time, and connection time indicates the associated intervention time, which should be mapped to the delay-tolerant and real-time application of sensor network integrated to the Internet. The features in Table 1 can be implemented within the QoS gateway located as the interface between the sensor network and the Internet.

The QoS components in a DTN gateway possess great potential in mapping the varying QoS mechanism employed by the different networks. DTN is able facilitate the cross-domain QoS that provides a mapping mechanism between the different QoS mechanism implemented in both sides of the network. The first QoS tool which can be within the DTN architecture is the priority class. The bundle protocol in a DTN architecture provides three levels of bundle delivery, which are low, medium and high. These levels are associated to the concept of priority classes which matched the flow/traffic class identification in the QoS management function shown in Table 1. Secondly, the DTN architecture offers a set of delivery options based on bundle status reports, which can facilitate QoS provisions. The featured delivery options, such as bundle receptions, custody forwarded and bundle deletion and delivery may assist in managing the QoS related to scheduling, flow control and QoS routing.

3.3 End-to-end Communication

The end-to-end data flows from a WSN to its users impose various transmission times in different communication layers. As mentioned earlier, the network supports Supple Service Model [42], which provides periodically collected sensorial or geographical information. As stated in [42], this model can be either interactive if it is query-based, or non-interactive if the user subscription defines a semi-continuous flow of data at regular intervals. Therefore, the transmission time include the communication between a sensor node to gateway, gateway to Internet router, and Internet router to another WSN gateway. Apart from these transmission times, the communication time is further augmented by processing delays and queuing delays within gateway devices.

Table 2: End-to-end communication

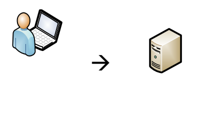
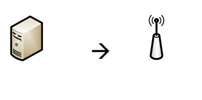
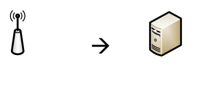
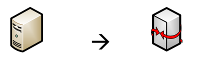
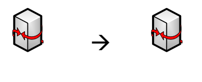
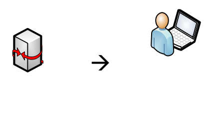
	Source and Destination	Communication Layers	Description
1		Local user and gateway	Local users initiate requests and gain responses to/from sensor nodes through WSN gateway
2		Gateway to Sensor node	The gateway device acts as the sink that has a direct connection with the sensor nodes
3		Sensor node to Gateway	Sensor node sends captured data to the gateway device
4		Gateway to Internet router	Gateway device passes data to an Internet router
5		Internet router to Internet router	Internet propagation based on no. of hops
6		Internet router and Remote user	Remote users communication via Internet routers

Table 2 illustrates the end-to-end communication in the network.The table depicts the steps involved in different layers of the network, i.e. ranging from requests initiated by a user, to communication between nodes which are constituents of different WSNs, until a response is received by the user.

4 NETWORK MODELLING AND SIMULATION

In this section, the simulation work conducted on OPNET Modeler [43] is presented. OPNET, or Optimized Network Engineering Tools, is a computational software used to model and simulate data networks. The simulation tool strives to accurately model and predict the behaviour of real environment in different scenarios. Furthermore, OPNET Modeler is equipped with various tools to enable simulation of heterogeneous networks that use different communication protocol, hence has become one of the most prominent discrete event simulator to design, develop and test network protocols. In this section, a description of the simulation setup is first provided, followed by the simulation cases indicating the design parameters of the study.

4.1 Simulation Setup

Figure 4 shows the OPNET network modelling environment. The network model is generated based on the reference architecture in Figure 1. A wireless network with one gateway is simulated and the wireless nodes which communicate directly with the gateway are organized in a star topology.

In OPNET, a network that carries different applications can be setup. Hence, 'Application Config' and 'Profile Config' [44] is defined, in order to represent the application associated with the network. The simulated application service is comparable to Supple Service Model which provides periodically collected sensory or geographical information to users. In addition, there are also user interactions through query-based when real-time information is needed.

A traffic generator is simulated to represent steady traffic flows in one-hop transmitting data directly to the gateway. As shown in Table 3, two classes of traffic classes EF and AF are generated, in order to simulate the co-existence of real-time and delay-tolerant traffic.

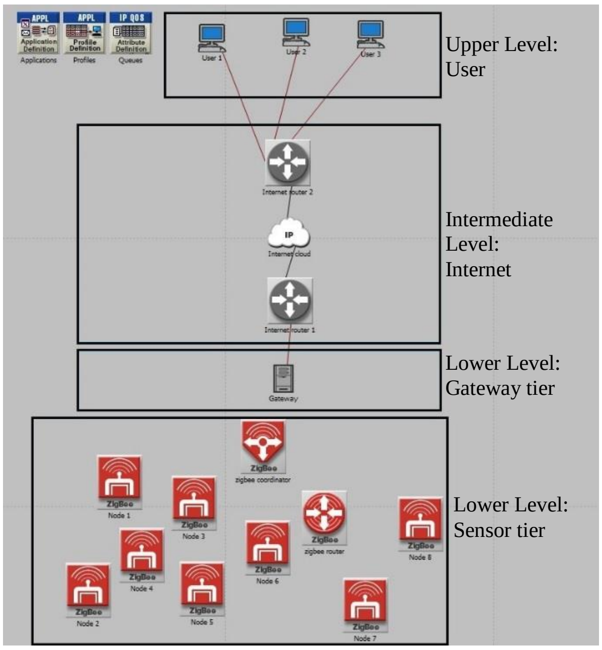


Figure 4: OPNET environment

Table 3: Simulation parameters in OPNET

Parameters	Value	
Topology	Star	
Simulation time	10 hours (1st simulation) 1 hour (2nd simulation)	
Buffer Size	100 kbytes (1st simulation) 50 kbytes (2nd simulation)	
Traffic characteristic	EF	AF
Traffic types	CBR	FTP
Traffic distribution	20%	80%
Inter-arrival time	50 sec.	20 sec.
Traffic distribution	50%	50%
Inter-arrival time	20 sec.	20 sec.
Traffic distribution	80%	20%
Inter-arrival time	20 sec.	50 sec.
Packet size	40 bytes	

EF traffic is generated using User Datagram Protocol (UDP) and Constant Bit Rate (CBR) traffic. AF traffic is provided using Transmission Control Protocol (TCP) and File Transfer Protocol (FTP) traffic. UDP is usually preferred over TCP in a typical multimedia applications where timeliness is of greater concern than reliability [40].

4.2 Simulation Cases

The aim of the simulation is to point out the pitfalls of integrating the WSN to the Internet without considering the QoS requirements of packet timeliness and reliability. Next, the proposed differentiated service is implemented, and subsequently the network performance under different traffic distributions is evaluated.

For its resource allocation scheme, the gateway implements some queuing discipline that governs how packets are buffered while waiting to be transmitted. Hence, for the first simulation, two typical scheduling scheme, namely weighted fair queuing (WFQ) and priority scheduling (PQ) are simulated, in order to treat packets with high and low priority differently. In the WFQ policy, one queue is maintained for each priority class. Weights are associated with the classes based on their importance. Queues are then serviced (i.e., packets are taken from the queues and sent on the outgoing line) at rates based on their weights. For instance, if the high priority queue was assigned a weight of '2', and the low priority queue was assigned a weight of '1', then two packets will be sent from the high priority queue for every one sent from the low priority queue. On the other hand, in the PQ policy, all high priority packets get sent before any low priority packets. The low priority transmission will be pre-empted if any new high priority packets arrive. The aim of the simulation is to highlight the arising issues when timeliness and reliability requirements are not considered carefully in these typical PQ and WFQ. The simulation duration is set to 10 hours for 100kByte gateway buffer size. The buffer size is set relatively small, which will allow easier observation of the scheduling effects. Equal traffic distribution is generated for this simulation case.

Then, the effect of differentiated service is investigated by observing the network's ability to meet different QoS requirements. Therefore, in the second simulation, the framework performance is assessed by monitoring the packet queues under different traffic distribution, i.e., different percentage of EF-AF traffic. In the simulation, EF-AF distribution of 50%-50%, 20%-80%, and 80%-20% are generated. Inter-arrival data rate of 20 seconds is used for an equal EF-AF distribution, while 20 seconds and 50 seconds are set to simulate the 80%-20% traffic distribution. Simulation time is set to 1 hour, and smaller buffer 50kByte buffer size is configured.

5 RESULTS

In this section, the results based on different simulation cases are discussed. In addition, descriptions of CarTel [23] vehicular network project is presented, to serve as an example case and to show the applicability of the proposed framework in a real environment settings.

5.1 Typical Gateway Scheduling

Figure 5 shows the amount of dropped traffic when typical PQ and WFQ scheduling are used within the gateway. The graph shows the amount of packets that were dropped due to buffer overflow. Note that traffic dropped for both scheme occur at almost a similar rate, due to the small weight difference among packet types. As packets are treated merely as high and low priority, it is observed that the high priority queue has a lower drop rate than the low priority. However, this should not be the case when the reliability requirement is of interest. Packets with reliability-constraint cannot tolerate loss or can only tolerate a small percentage of loss, hence should have a high packet delivery percentage.

On the other hand, the proposed differentiated service combined with the buffer eviction policy aims to address both timeliness and reliability requirements. Hence, to ascertain its ability to meet heterogeneous QoS requirements, the way AF and EF packets arrive to the users will be assessed.

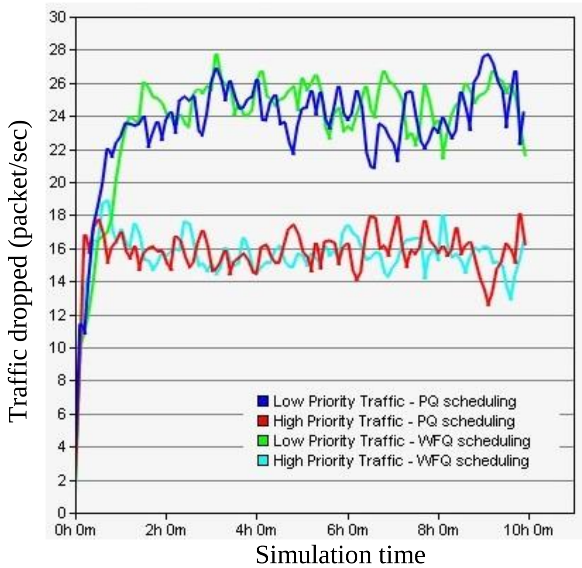


Figure 5: Traffic dropped for PQ and WFQ scheduling

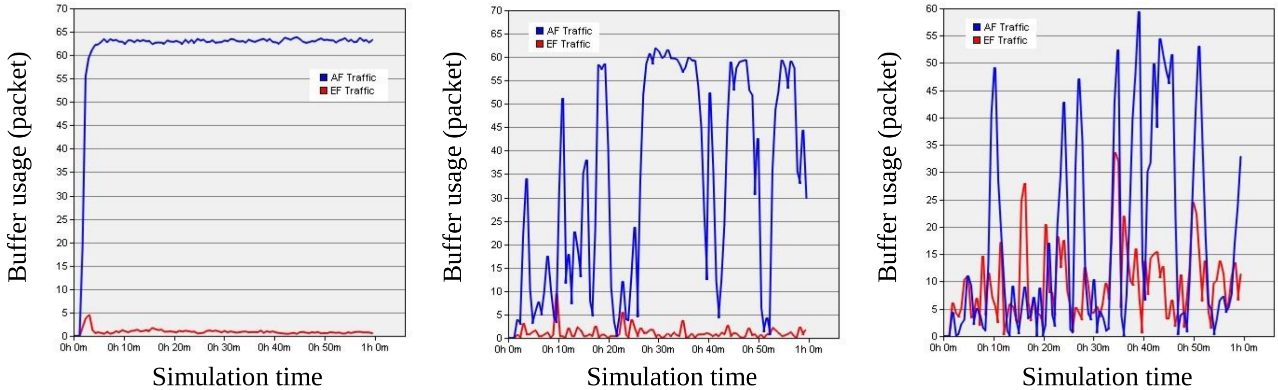
5.2 Performance with Differentiated Service

In the second simulation, the way predefined QoS metrics are affected by the service differentiation is analysed. Furthermore, a discussion on the service differentiation's ability to meet both types of traffic QoS requirements is provided herein.

The first statistic is buffer usage, defined as 'the number of packets waiting in the queue at any time during the simulation'. As shown in Figure 6, there are significantly greater AF packets waiting in the queue for the entire simulation, while EF packets were seldom kept waiting. However, the buffer usage of the EF traffic increased for the 80%-20% distribution, due to the higher data rate that introduced greater volume of data in the buffer. While the EF packets are forwarded to the output traffic, the AF packets occupy larger buffer space. Hence, the results indicate that both EF and AF packets achieve their QoS requirements.

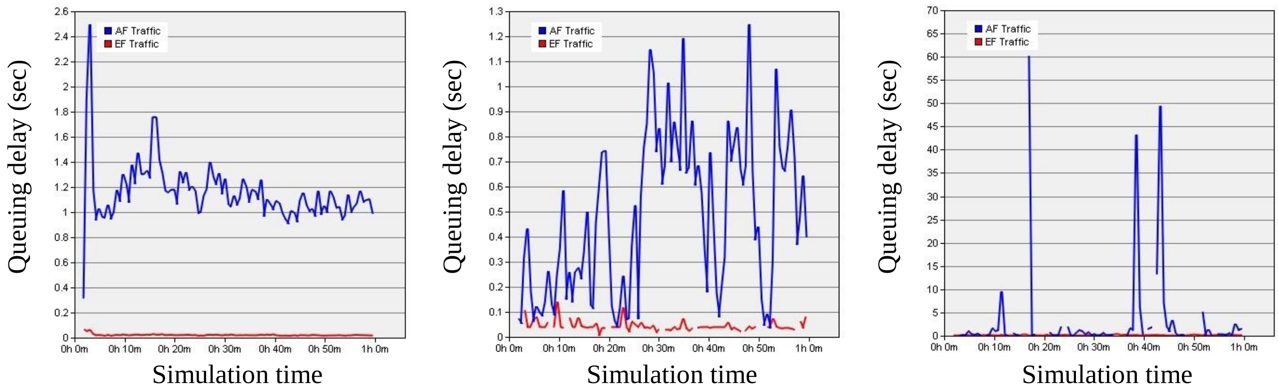
The second statistic is queuing delay, i.e., the duration packets have to wait in the queue before being sent. As shown in Figure 7, due to the service differentiation, the AF traffic experienced a longer queuing delay than the EF traffic, especially in the 80%-20% distribution. The result also shows that the differentiated service provides a low delay bound for EF traffic for all traffic distribution. This indicates that the EF traffic with timeliness requirement goes first to be forwarded to the external network regardless of the order of arrival.

Lastly, traffic dropped, defined as 'the number of packets dropped due to buffer overflow', is investigated. Generally, as shown in Figure 8, it is



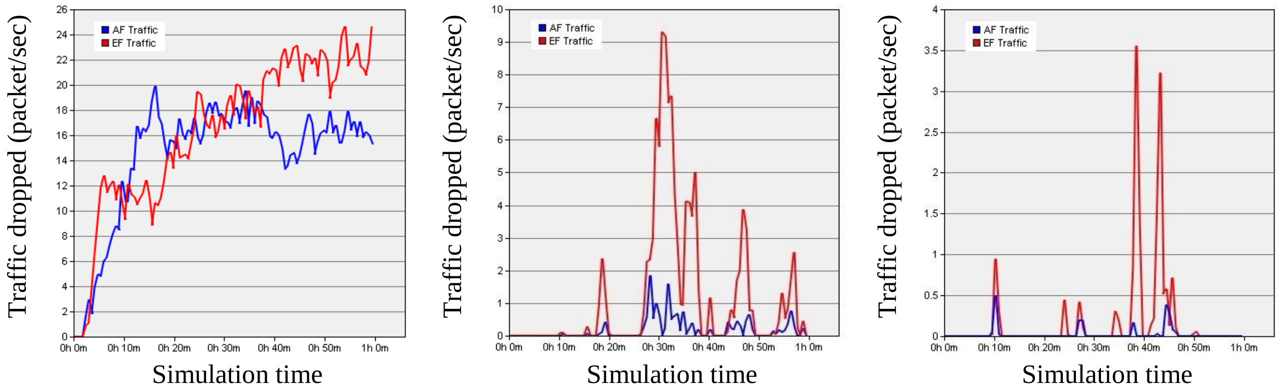
(a) 50% - 50% **(b) 20% - 80%** **(c) 80% - 20%**

Figure 6: Buffer usage (packet) vs simulation time for EF and AF traffic



(a) 50% - 50% **(b) 20% - 80%** **(c) 80% - 20%**

Figure 7: Queuing delay (sec) vs simulation time for EF and AF traffic



(a) 50% - 50% **(b) 20% - 80%** **(c) 80% - 20%**

Figure 8: Traffic dropped (packets/sec) vs simulation time for EF and AF traffic

observed that the AF traffic has a lower drop rate than the EF queue. Although the EF traffic are serviced first, they are often lost before delivery. This is acceptable as the EF traffic has more tolerance to packet losses as compared to the AF traffic. On the other hand, while the AF packets travel slower (due to higher queuing delay), they are delivered with much more reliability. In addition, due to constrained buffer capacity, a small percentage of EF packets are evicted due to high storage pressure. The reliability of both AF and EF packets can be improved with larger gateway buffers.

The results suggest that when the service differentiation and buffer eviction policy are used, both the timeliness and reliability QoS requirements imposed by different packet types can be met. The scheme ensures low delay bound for EF packets, while maintaining low packet loss for AF traffic. Hence the framework is suitable for a network with mixed priorities and varying QoS requirements in terms of timeliness and reliability.

5.3 Example Cases

As discussed in Section 2.2, there are various WSN applications that have two kinds of existing data packets. The examples briefly discussed in the section are smart animal farming and intruder detection system. Moreover, in many applications of wireless multimedia sensor networks (WMSN) [45], a sensor node may have different sensors that gather different data of different sampling rate. In addition, the potentialities offered by the IoT make the development of a wide range of applications possible. These applications can be categorized into transportation and logistics domain, healthcare domain, smart environment domain, and personal and social domain [46].

In order to show the applicability of the QoS model to WSN applications, an example case with mixed traffic nature is examined and compared with the simulation environment. An application consisting of different data types can be inspired from the MIT CarTel project [23], which collects multiple real-time and delay-tolerant data within a vehicular network. In this network, a mobile sensor computing system was designed and implemented to collect, process, deliver, and visualize data from sensors located on mobile units such as automobiles. A node in the WSN application is a mobile embedded computer, coupled to a set of sensors. Each node gathers and processes sensor readings locally before delivering them to a central portal, where the data is stored in a database for further analysis and visualisation. Data on cars is delivered to a portal, where users can browse and query it via a visualization interface and local snapshot queries.

The application provides a simple query-oriented programming interface, and handles large amounts of heterogeneous data from sensors. These may include GPS data about road traffic speed and delays, the quality and prevalence of Wi-Fi access points on drive routes, images from an attached camera, and on-board automotive diagnostic data. In addition, the nodes rely primarily on opportunistic wireless connectivity to the Internet, or to "data mules" such as other mobile nodes to communicate with the portal. The system's applications run on the portal, using a delay-tolerant continuous query processor to specify how the mobile nodes should summarize, filter and dynamically prioritize data. All of the collected and processed data are accessible to users via a web site, through the portal [23].

Therefore, a complete vehicular system involves two main components; First, data collecting and processing in the sensor network. Second, conveying processed and raw data to the Internet for users' queries. In the perspective of our integrated QoS framework, focus is given only at the second part of the system, i.e., conveying the mixture of traffic data to user in the Internet through the portal. The portal acts as a sink for all data sent from the sensor nodes, hence, is comparable to the QoS gateway in the simulation. Therefore, it is assumed that the vehicles connected to the portal forms a star configuration, and the collected data create traffic queue on the sensor network gateway.

In order to provide a comparison between this example case and the simulation scenarios, the two major data traffic from the application can be defined as the real-time and delay-tolerant traffic. The real-time data is defined as the GPS data from the vehicles – they need to be collected timely as they are used to model traffic delay; however they do not necessarily need to be sent reliably. On the contrary, the data that detects road surface anomalies such as pot holes are categorized as the delay-tolerant data – they require high reliability to avoid false alarm, but do not need to be sent quickly.

Furthermore, as featured in [23], the system enables users to specify the way sensor nodes should collect, process, and deliver sensor data. These user queries specify the data type that must be acquired in a predefined rate, how the data should be sub-sampled, filtered, and summarized on the mobile node, and the priority order that the results should be sent to the portal. At the same time, as sensors often produce more data than the network can promptly deliver to the portal, applications on the portal need a method to specify the way to prioritize data through network layer buffering. The system matches the supple service model as simulated in this paper, which provides periodically collected sensory or geographical information to users, as well as providing query-based user interaction when real-time information is needed. Therefore, the traffic distribution (20%-80%, 50%-50%, 80%-20%) used in the simulation is associated either to the following factors – the varying Internet users' queries specifying different traffic prioritization at varying data rate, or the randomness of the data delivery to the portal due to fleeting network connectivity and nodes' mobility.

Table 4: Design parameters in future work

1. System Dimensions:	
Traffic dimension	*N* number of mixed priorities traffic (EF, AF1, AF2, AF3)
Data flow rate	Different data rate for different traffic types (application dependent)
2. Network Architecture:	
Node density	*n* number of nodes over different area sizes
Gateway capacities	buffer size, scheduler
3. System Variants:	
Communication protocol	802.15.4, ZigBee, 6LowPAN
IoT architecture	TCP/IP Overlay, Full IP Stack

6 FUTURE WORK

The studies on WSN-Internet integration described in this paper have primarily focused on a single isolated WSN interconnected to the Internet. However, the major goal of IoT is to integrate the islands of WSN into a globally interconnected infrastructure, moving from Intra-net to Inter-net of Things [47]. Hence, the future work in this study will be conducted for scenarios closer to the notion of IoT, which involves interconnections of multiple WSNs through the Internet backbone. The current and future activities include:

Generic model development: A generic QoS model is currently being developed. This allows the model implementation to accommodate various WSN situations involving greater number of traffic types. This includes AF traffic with multiple priorities (AF1-AFn). In addition, the model will also allow testing of broader traffic dimensions including traffic which has both real-time and reliability strict requirements.

Comprehensive model testing: The activities include testing the system performance under different system dimensions and variants that, as shown in Table 4. These traffic are associated with specific data rate, for example, ranging from data arrival every 5 seconds to a data every 1 hour, which will be defined based on common WSN applications. In addition, a variety of WSN protocol stacks (e.g., ZigBee, 6LowPAN) that enables communication within IoT will also serve as the design parameters of this research. Another approach is to compare the model to existing QoS protocol outside the domain of WSN.

QoS model implementation: To test the applicability of the QoS model, its performance on WSN applications with mixed traffic nature will be examined. Apart from a more extended model implementation to the example case of vehicular network, several WSN applications will be selected and will serve as the cases of the study.

DTN modelling and validation: This research will further involve modelling and analysing the DTN network for WSNs integration. The main activity will be the validation and verification of QoS model under real-setting and open federated WSN testbeds [48, 49], in order to test the QoS model for interconnection of multiple WSNs. In this activity the influence of Internet propagation, for example, under various number of router hops or intercontinental distance, will also be studied.

7 CONCLUSION

In this paper, a QoS framework for integrating WSN to the Internet is proposed. One of the main objectives of the framework is to achieve differentiation of traffic classes within a WSN, in order to manage real-time packets with timeliness constraint and delay-tolerant traffic with reliability constraint. Apart from providing guaranteed QoS for a mixture of traffic in the network, the proposed integrated QoS model is also geared to achieve seamless interworking between WSN and the Internet.

This paper evaluates a fraction of the proposed QoS model, by assessing the system performance under service differentiation on the gateway level. First and foremost, through simulation in OPNET Modeler, the drawbacks of using PQ and WFQ scheduling is identified. It is observed that the typical resource allocation schemes such as PQ and WFQ are not suitable for WSNs with a mixture of traffic types. On the other hand, further simulations focuses on the way real-time and delay-tolerant packets are delivered under the proposed service differentiation and buffer eviction policy. The preliminary results suggest that when service differentiation and buffer eviction policy are used, the QoS requirements imposed by different packet types can be met, i.e., real-time traffic achieve low bound delay while delay-tolerant traffic experience a lower packet dropped. In addition to the presented results, an example case of a vehicular network is discussed in order to demonstrate the applicability of the QoS mechanism in a WSN application with mixed traffic nature.

This paper also distinguishes both the Internet QoS and WSN QoS strategies in order to identify the QoS requirements for the integration. It is envisioned that the gateways that interface WSNs to the Internet should run a QoS mechanism that link the network-level QoS mechanism from both WSN and the Internet. Hence, DTN-gateway solution is proposed to achieve a seamless QoS interaction between the Internet and WSNs. This paper explains the QoS mapping on the gateway connecting both networks and the future works relating to the integrated QoS objectives.

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