Quality of Service Modelling for Federated Wireless Sensor Network Testbeds Gateways

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Abstract— **The federation of WSN testbeds has brought forward the requirement for a QoS implementation, in order to ensure efficient and reliable end-to-end communication between testbeds' users and testbeds' facilities. Nowadays, the Internet has become the de facto standard for establishing remote connectivity between these testbeds. However, as the mechanism of QoS support in WSNs may be very different from that in the Internet, it is necessary to address the differences between the QoS employed in the Internet and the QoS required in WSN testbeds for the purpose of QoS provisioning. Hence, our work focuses on generating a QoS model for testbed gateways by merging the QoS perspectives from both networks. Moreover, this research will also focus on validating the modelled QoS through QoE measurements, as the network-level QoS parameters can be translated into user-level QoE perception.**

Keywords-QoS modelling; WSN testbed; federation; gateway

I. INTRODUCTION

In the recent years, there has been an increasing trend to develop wireless sensor network (WSN) testbeds which aims at providing the environment for researchers to conduct experiments [1-3]. Moreover, these testbeds which enable researchers to evaluate and validate their WSN-related work are integrated to the Internet to allow remote access to its users. Although these testbeds provide tremendous benefit to researchers, they are usually limited in size due to hardware costs. Thus, there exists a growing trend to interconnect small testbeds to provide federated testbeds with large-scale testing facilities [4]. However, while a good deal of research and development has been carried out in testbed architectural design, there is a glaring lack of studies on network performance in the environment of federating WSN testbeds.

One of the major challenges in federation of testbeds is to provide reliable and efficient connection between interconnected testbeds. Therefore, network performance indicator such as Quality of Service (QoS) must be taken into account in federating these testbeds, in order to ensure reliable and efficient real-time experimentation for testbed users.

Traditional QoS, such as employed in the Internet, mainly results from the rising popularity of end-to-end bandwidth–hungry multimedia applications, and are defined using certain parameters such as packet loss, delay, jitter and bandwidth. On the contrary, the metrics concerned such as available bandwidth and delays may not be pertinent in most WSN environment as some WSN applications could be latency-tolerant or transmitting very small packets. Moreover, in some WSNs, it is typical that the amount and quality of information is more important in WSNs [5].

The touching point between a testbed and the Internet is the gateway. Thus, it could become the main element in contributing to the performance of the federation. In order to allow for greater capabilities of fixed and simple gateways, there has been an increasing trend to turn the gateways into ones with greater capabilities. Research concerning smart gateways [6] or modular gateway may benefit the QoS significantly.

Furthermore, open federated testbeds usually allow access to multiple users to testbed resources for real-time experiment and observation. Consequently, testbeds operator's main interest would also include the way users perceived the testbeds usability, reliability, quality and time-worthiness. Hence, a further step beyond provisioning QoS is observing its users' Quality of Experience (QoE).

Therefore, in this research, we are inspired by two major goals; (1) to provide a solution for QoS mechanism to run on top of testbed gateways that satisfies stringent QoS requirements of an environment of federated testbeds, and (2) to devise a scheme for validating and verifying the network performance under the modelled QoS.

The remainder of this paper is organized as follows. Section 2 will give an overview of the research problem domains. Next, the design of our study is presented in Section 3. Finally, Section 4 concludes the paper.

II. PROBLEM STATEMENT – QOS FOR TESTBEDS FEDERATION

Due to the significant differences between WSN and the Internet, the QoS requirements generated by both networks may be very different. Indeed, existing research has concluded that the end-to-end QoS parameters employed in traditional data networks such as the Internet are not sufficient to describe the QoS in WSN [7, 8].

In this section, we distinguish the QoS requirements in WSN from the QoS requirements in the Internet, followed by an overview of integration QoS on the gateway device. This is followed with an overview of QoE for testbed users.

A. *QoS Support in WSN*

The two perspectives of QoS in WSNs were described in [7] to focus on the way the underlying network can provide the QoS to different application:

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Application-specific 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 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.

Network QoS

From the perspective of network QoS, the QoS parameters are chosen based on how 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. However, since WSNs is envisioned to be employed in diverse applications, a number of works in the literature suggested that every different application imposes different QoS requirements.

B. QoS Support in the Internet

RFC 2368 [9] definition on QoS-based routing in the Internet characterizes QoS as a set of service requirements to be met when transporting a packet stream from the source to its destination. 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 should be able to handle different traffic streams in different ways, this necessitates traffic engineering approach which classifies users into classes with different priority.

IntServ model and DiffServ model 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 IntServe, QoS in DiffServe is achieved via some strategies such as admission control, traffic classes, policy managers, and queuing mechanism.

C. Integration QoS

Several studies have demonstrated network performance testing and QoS measurements of WSN-Internet integration. The performance is typically measured using several predominant QoS metrics, focussing on the QoS implementation on the gateway side of WSN integrated to the Internet.

The QoS is commonly provided by an integration controller which runs software modules and able to reconfigure the QoS parameters on the network edge router. In this typical application-level gateway approach, the performance is evaluated in terms of inter-arrival time (the time between adjacent packets), packet delay, latency or round-trip rate (RTT, the time taken by a packet to travel from the source to destination) and cumulative distribution function of the RTT.

Moreover, in a non-trivial network, a packet will be forwarded over many links via many gateways. Gateways will not commence forwarding the packet until it has been completely received. In such a network, the minimal latency is the accumulation of the minimum latency of each link, the transmission delay of each link and the forwarding latency of each gateway. In practice, this minimal latency is further augmented by processing and queuing delays. Whereas processing delay occurred while a gateway determines what to do with a newly received packet, queuing delay occurs when a gateway receives multiple packets from different sources heading towards the same destination.

D. QoE for Testbed Users

Ideally, in order to provide unifying testbed facilities for experimentations, federated testbeds allow access to multiple users over the Internet at any given time. The main objective and other major attributes of a testbed pose certain critical questions: a) how could the network ensure good users' experience? b) how does the network manage its resources to do so? c) how does the network maintain reliable connection for users' real-time experimentation? d) how does the network cope with the demand from the testbed users for a large number of nodes for their experiments? This calls for QoS mechanism that takes into consideration the QoE; tying together user perception, experience and expectation to the application combined with the network performance [10].

III. Design of the Study

In this section, we discuss the tasks involved in designing the QoS model. Primarily, the QoS modelling will be carried out using a network modelling simulation tool, namely OPNET Modeler. In order to provide a means of validation, we propose that the network performance measurement under the modelled QoS shall be conducted over physical federated WSN testbeds linked to an Internet testbed.

A. QoS and QoE Requirement Analysis

The QoS and QoE mechanisms discussed in the previous section are mainly employed in separation. To the best of our knowledge, there is no precedent work that has considered merging the aforementioned QoS and QoE perspectives into one. Hence, we target to develop a solution for QoS provisioning in an environment of federated WSN testbeds by consolidating Internet QoS, WSN QoS and testbed user's QoE.

Therefore, we first conducted a QoS and QoE requirement analysis by taking into account various characteristics from the networking and users' perspectives. In this task, we map our findings on the requirement analysis from both network and users perspectives [11], in order to identify the dominant QoS and QoE metrics that are crucial for the federation.

Hence, the requirement analysis includes the following network characteristics:

1) End-to-end: In general, WSN testbeds offer resource reservation to their users. This implies that one end of the application is a testbed user, and the other end is a single node within the testbed. A QoS implementation is needed to ensure end-to-end network performance throughout an

experimentation session and any connection issues should not jeopardize the validity of the experiments in any way. In addition, the network's requirement on end-to-end performance also implies strict QoS requirements in both WSN and the Internet.

2) Criticality: Experiments on testbeds should be achieved with high information reliability. Thus, this also suggests that packet losses cannot be tolerated in any extent.
3) Bandwidth Requirements: Although bandwidth availability is not the main concern in most WSN applications, it is of great importance in the Internet. Furthermore, bandwidth may be an important factor for a group of sensors with the bursty nature of sensor traffic. Thus bandwidth plays a vital role in provisioning QoS in the testbed environment.
4) Interactivity: Testbed environments typically are based on query-driven approach, i.e., queries are made to reconfigure sensor nodes and manage resources. These commands require high reliability from the network, thus implying QoS requirements in terms of timely and reliable response from the testbed side.
5) Delay Tolerance: The network tolerance of delay may be based on the models of experiments offered by the testbed. However, in an environment of federated testbed, the end-to-end delay might be a critical factor due to the best-effort nature of the Internet.
6) Network Dimensions: When building testbeds federations for scale, the interconnection of testbeds can be of closely located testbeds, or it could expand to be of large intercontinental federations. The Internet's capability to deliver packets from one end to another plays a huge factor in the overall network performance. In addition, the total number of nodes may affect network performance as the volume of traffic is more likely to increase as the number of nodes grows.

B. Federation Network Model

Figure 1 shows the reference architecture for the federation WSN testbeds, whereby gateway devices reside in the 2nd-tier of sensor network testbeds level.

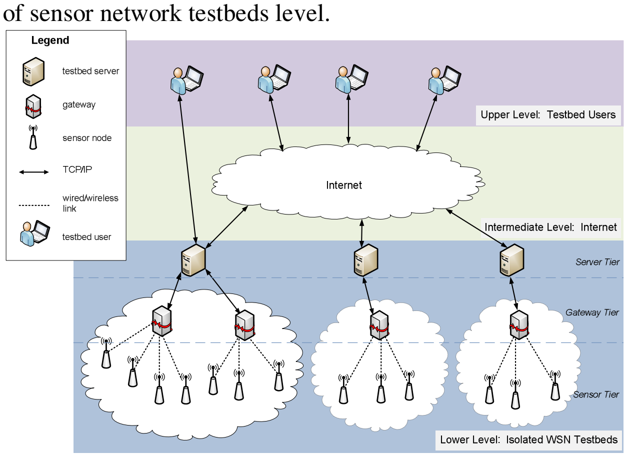

Figure 1: Reference architecture of federated WSN testbeds

Testbed server, which represents a single testbed, forwards application for users from the Internet to the gateway for node access. On the other hand, the gateway that serves as the interface between a testbed server and the sensor nodes, mainly responsible for packaging high-level user queries to network specific directives and returning filtered portions of the data to users. Therefore, being in a unique position as having the full knowledge of and control over both WSN testbed and the Internet, the gateway plays a vital role for the QoS provisioning purpose.

The main challenge concerning the interconnection between Internet and a WSN testbed is the requirements to provide access to each sensor nodes through the TCP/IP based network. Hence, we focus on distinguishing the QoS factors from various network levels, and identify those pertinent to the gateways that act as the main interface between an the Internet and a testbed. The QoS factors involves in an event of sending or receiving messages [12] over the network include the different levels as depicted in Figure 1, which may include:

1. The application on the sending/receiving sensor nodes to/from the gateway device (gateway lookup, encoding/decoding, interrupt handling, propagation)
2. Processing delay inside the gateway device (interrupt handling, propagation LAN/WLAN, packet translation)
3. Processing delay inside the testbed server (packet translation, address lookup)

C. Our Proposed Federation QoS Solution

We propose to employ a system capable of differentiating traffic classes. Different priority traffic placed in different queues could contribute greatly to the success of the QoS solution. Hence, to be able to place the traffic into a specific queue, we need to classify the traffic. Hence, classification is one of the basic functions performed on a packet when it arrives at a QoS enabled gateway, which is then followed by remarking of packet. We propose that the traffic classification is implemented on various basic testbed functionalities and experimentation tools typically offered by WSN testbeds, which may include user registration, resource/node reservation, topology selection, job scheduling/management/cancellation, files uploading, data retrieval, and nodes programming.

Classification and remarking are the basic building blocks for the QoS. Therefore, we will test the network performance by looking into test cases with combination of these two aspects, for example by implementing priority for retrieval of data and remarking for node reservation.

D. Network Modelling and Simulation on OPNET

In our preliminary testing, we have generated a network model and simulated the federation model using OPNET Modeler [13]. We have conducted simulations of testbed networks under different loads to three different scenarios:

<u>Isolated Testbed</u> -This configuration represents a single testbed in isolation. Local users gain direct connection to the sensors through the gateway, which obtains access to the wireless network through an access point.

<u>Testbed Integrated to the Internet</u> - This configuration represents a single testbed connected to the Internet.

<u>Federation of Two Testbeds</u> - This configuration represents two testbeds interconnected to the Internet.

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The main objective of the simulation is to compare the network's performance for isolated and integrated environment. Although this simulation did not involve any direct QoS implementation, we believe our finding from the simulation activities give an important insight pertinent to QoS provisioning, hence facilitates for further experimentation for our federation QoS modelling. We evaluated the network performance based the following QoS parameters: packet received against packet sent (reflects packet loss) and end-to-end delay.

<u>Received Traffic:</u> Figure 2 depicts the amount of traffic received (in packets/sec) against the amount of traffic sent (in packets/sec), for all three testbed scenarios. In both cases of an isolated testbed and a testbed integrated to the Internet, as expected, the amount of traffic received proportionally increased as more traffic is sent to the network. However, there was a point in the graph where the amount of traffic received flattened, despite having a continual increase of the traffic sent. Most importantly, at a particular point, the amount of traffic received in a WSN-Internet integrated testbed tend not to increase as rapidly as those in an isolated WSN testbed. A way to interpret this is to presume that the network has reached its full capacity in terms of link bandwidths, traffic queues or devices' processing power; therefore, it could not deliver any more traffic to its destination.

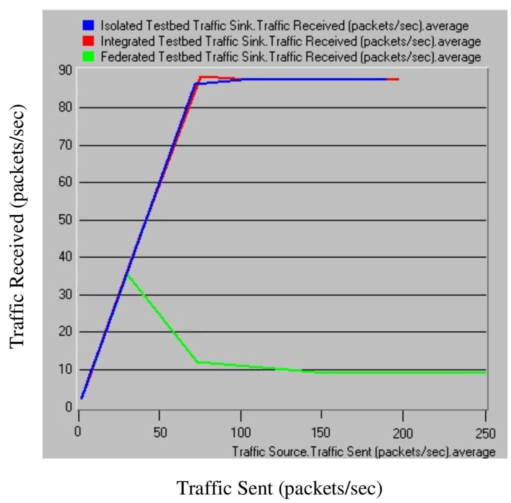

Figure 2: Traffic Received as a function of Traffic Sent

On the other hand, we have observed a major difference in the resulting graph of the federated testbed scenario. The number of packet received within the federated testbed started to decrease at a certain amount of packet sent. This could be explained by the fact that single gateway or QoS-enabled gateway node may create a bottleneck over the network. Furthermore, since network capacity and number of hops are a major concern in the Internet, there is a higher probability of having packet losses as more and more packets transit on the Internet.

<u>End-to-End Delay:</u> Next, we run a simulation on the end-to-end delay for both scenarios, against traffic sent. Once again, the result obtained showed a significant difference between federated testbed scenario and the other two testbed topologies. It was observed that the federated testbed scenario by far demonstrate a very high end-to-end delay. In addition, as per our expectation, the testbed integrated to the Internet tend to record slightly higher delays, as compared to isolated WSN testbed. The ensuing graph is depicted in Figure 3.

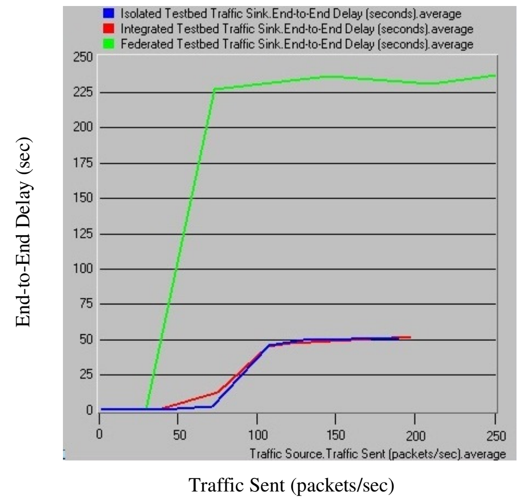

Figure 3: End-to-End Delay as a function of Traffic Sent

Our results have shown that due to its size, and particularly its unpredictable nature, the Internet does introduce a level of service degradation (i.e., higher packet losses and delays) when it is subjected to high traffic load. This could pose a problem for mission-critical WSN applications where there is a need for predictable performance. Similarly, this must be taken into account especially when the notion of federating WSN testbeds featuring several thousands of nodes and multiple users is of interest. Hence, the introduction of an end-to-end QoS, which ensures that packets are being delivered in a reliable and timely manner in both the WSN testbed and the Internet, could be a solution to this matter.

E. Testbed Experimentation – Linking together WISEBED and PlanetLab

One of the primary goals of this research is to assess the QoS model in a real wide area network. Hence, there is a need to analyze the performance of the QoS in a real world scenario by conducting necessary network traces and measurements. Therefore, once we have implemented the QoS on the gateway, we want to evaluate the model in a bigger, real-world environment. We need a tool to read incoming packets from the live-traffic Internet to test how well our QoS model handle users' traffic. An Internet testbed such as PlanetLab is an ideal testbed for this purpose due to its dispersion.

Therefore, in order to complete our modeling architecture, we aim to generate a federation across an open federated WSN testbed, namely WISEBED [14], and PlanetLab [15], hence providing the platform for real-time traffic simulations. WISEBED offers extension to its originally nine-federated testbeds, as WISEBED-compatible testbed can be established by researchers by employing Wisebed Runtime [11, 16].

Therefore, we propose to utilise Wisebed Runtime to be able to interconnect our network to WISEBED facilities.

As shown in Figure 4, we will devise the framework for the interconnection that will serve as the main platform to test our QoS modelling. The technical challenge is to construct the tunnelling mechanism [17] using tunnelling protocol such as Generic Routing Encapsulation (GRE) [18], to allow communication between our testbed gateway to the PlanetLab node.

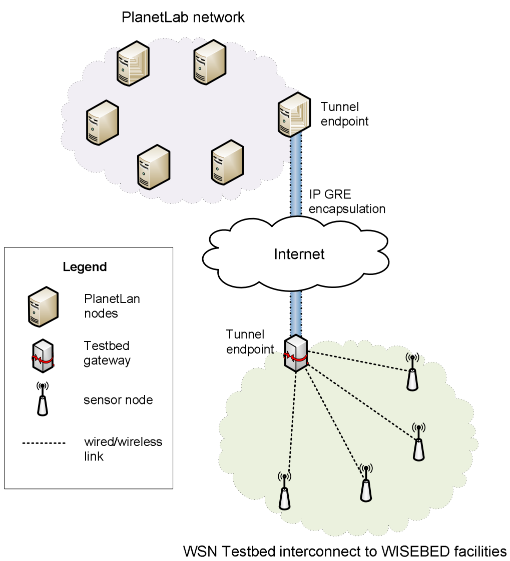

Figure 4: Network Architecture: the tunnelling communicating testbed gateway and PlanetLab node

F. *QoS Model Performance Evaluation and QoE Verification*

The QoS measurements will be based on the dominant QoS metrics which will be defined from the QoS and QoE requirement analysis. The measurement will be conducted on the tunneling platform between the PlanetLab nodes and WSN testbeds over various traffic scenarios.

Whereas in our QoS model, we propose to employ a system capable of differentiating traffic classes, we will select a specific WSN application, such as indoor/outdoor and mobile applications, for the purpose of validation and verification using objective QoE [10, 19]. In this objective QoE mechanism, we will endeavour to find a QoE solution applicable to federated testbed environment. Specifically, we expect that the investigation on the impact of QoS on QoE will present a unified formula to express dependency of federation QoS and testbed user's QoE, hence allowing for adjustment to our QoS model.

IV. CONCLUSIONS

This paper provided an overview of a work in progress of QoS modelling for federated WSN testbeds. We have presented the significant differences between WSN QoS and Internet QoS, and will conduct a thorough QoS and QoE requirement analysis to formulate a QoS model for the federation. We advocate that gateways should run QoS mechanism that merges the network-level QoS perspectives from both WSN and the Internet, as well as the user-level QoE. In order to study the proposed model performance, we utilize OPNET Modeler as the modelling and simulation software. Furthermore, to complete our modelling architecture, we plan to federate PlanetLab and the open federated WSN testbed, i.e., WISEBED, to serve as the case to our study.

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