A Relay and Mobility Scheme for QoS Improvement in IoT Communications

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***Abstract*—Internet of Things (IoT) networks interconnect billions of devices of diverse data types such as multimedia and sensor data. These networks need to be able to offer services at high quality levels for a massive amount of users and smart objects. In this paper, we analyse the Quality of Service (QoS) of our Relay and Mobility Scheme for the Internet of Things (REMOS-IOT), which consists of *IoT objects* that provide several services such as video applications, CCTV monitoring and sensor data, *smart gateways*, which interconnect the smart devices, and a *cloud-deployed platform* which is used for resource management and decision-making to improve network quality. IoT services quality is improved by the implementation of an algorithm which considers QoS, devices locations and service relevance metrics, creating optimised clusters for the networked IoT objects. Objects are then attached to gateways or relay devices with better network quality, while the performance of poorly operating clusters is also improved.**

Keywords—IoT, smart gateways, QoS, performance, mobility.

I. INTRODUCTION

The Internet of Things (IoT) will reach 20.4 billion interconnected devices by 2020 [1]. Several new paradigms for IoT, such as new approaches for mobility, were identified in an IEEE report [2]. These paradigms open up new areas of research and development, crucial for mobile objects such as robots, buses, trains, drones, cars, wearables (e.g. smart watches, wrist bands) and smartphones, which include network performance, concurrency, mobility patterns, real-time coordination, data storage, etc. Metrics related to packet loss, delay, throughput and energy consumption are monitored to assess Quality of Service (QoS) levels of networked services, and are targeted by solutions concerned by performance and decision-making in IoT networks. These solutions employ, among other approaches, adaptation and scheduling techniques, clustering algorithms and connection control mechanisms [3]–[5] in order to achieve improvements in the quality of the offered services.

This paper introduces a novel RElay and MObility Scheme for the Internet Of Things (REMOS-IOT), which extends our previous work, the NETworking Scheme for sMart IoT gatewayS (NETSMITS) [6] by providing mobility support. NETSMITS did not consider mobility in the devices, or using other devices for relay.

As seen in figure 1, REMOS-IOT architecture is composed of IoT devices, smart gateways and a cloud-based

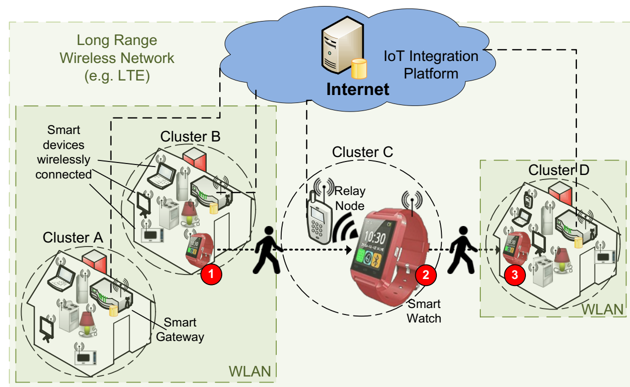

Fig. 1. REMOS-IOT Architecture

IoT Integration Platform (ITINP). Device distances to WiFi access points and LTE base stations are also considered in our solution, as well as other QoS metrics such as delay, packet loss and throughput. The focus of REMOS-IOT is to optimise devices clusters by attaching devices to optimal available smart gateways in the network or to other devices used as relay nodes, bringing better connectivity to devices and improving overall quality in the performance of the clusters. The architecture of REMOS-IOT allows IoT objects to provide and consume several services such as multimedia content and sensorial data. Smart gateways connect the IoT devices while ITINP provides the management of the smart gateways. Network Simulator 3 (NS-3)-based testing demonstrates that REMOS-IOT is capable of increasing communication performance of IoT devices. Our testing scenario contains a smart watch initially connected to a gateway in a WLAN (fig. 1 ①). The device moves towards another WLAN (fig. 1 ③), however, when moving, the device gets out of the reach of the available access points and uses another device as a relay node to maintain its connectivity (fig. 1 ②).

The rest of this paper is organised as follows. Section II presents related works and section III introduces the architecture and algorithms for the proposed REMOS-IOT solution. Section IV presents the setup of our simulations and discusses testing results. The paper is finally concluded with a section with conclusions and future work directions.

II. RELATED WORKS

Diverse QoS, clustering and mobility research works, related to IoT and our solution, are discussed in this paper.

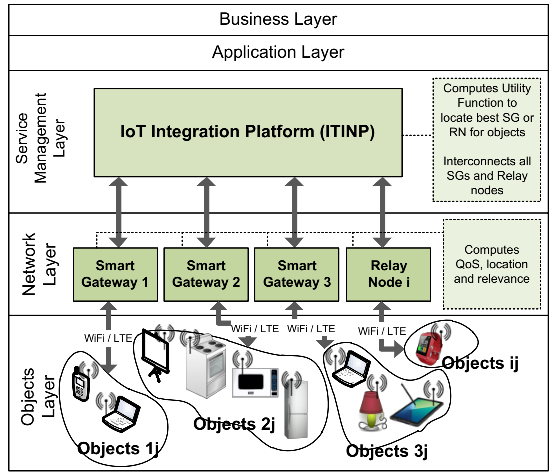

Fig. 2. REMOS-IOT Layered Architecture

A. QoS in the Internet of Things

IoT has important QoS constraints and therefore many approaches try to improve either network delivery or service quality. Authors in [4] proposed a three-layer QoS scheduling model for service-oriented IoT, including application, network and sensing layers. They employed metrics such as information accuracy, sensing precision, energy consumption, life-time of sensing networks, and cost to measure QoS levels of sensing networks. Authors also introduced a framework to evaluate services, networks, and sensing devices and a decision-making process with optimisation algorithms in each of their proposed layers. Results show that QoS in network and sensing layers provide improved values, and lifetime of nodes was extended.

A performance testing of the LoRa FABIAN, a network protocol stack and experimental network setup, deployed in Rennes, France, was performed in [7]. QoS of the network was measured in different scenarios, with communications between nodes and stations in terms of packet error rate (PER), Received Signal Strength Indicator (RSSI) and Signal to Noise ratio (SNR). Results show that the antenna location and elevation determine the quality of the network. Authors have yet to combine uplink and downlink traffic to verify if there is correlation between measurements, in order to select the best station for a node.

An adaptive congestion control mechanism for the Constrained Application Protocol (CoAP) in IoT was introduced in [8]. An adaptive congestion control was proposed to provide good performance delivery when there is increased packet loss. Authors have enhanced the congestion control mechanism by introducing traffic priority classes, adapting retransmission times and the back-off timer.

A predictive algorithm for dynamic virtual machine (VM) allocation in an IoT-Cloud environment was presented in [9]. The algorithm was incorporated into the novel Metascheduler Architecture to provide QoS in Cloud Computing (MACC). VM allocation is designed to conform with QoS constraints such as costs and deadlines. The solution also considered network heterogeneity and the low availability of certain resources. Results showed that the algorithm meets time and cost requirements. However, the authors did not consider admission control, different workload models, and migration of VMs.

Authors of [10] introduced a cost-effective analytical model for a finite capacity queueing system with pre-emptive resume service priority and push-out buffer management scheme. The IoT applications considered produce and consume delay sensitive information; the research focus was to ensure preferential treatment of highest priority delay sensitive data. Results demonstrated improvements in the performance of high priority traffic over low priority traffic and maintaining low blocking probability for high priority traffic. The buffer management scheme helped avoiding data loss of emergency data packets.

B. Clustering in the Internet of Things

Clustering of IoT devices is a common technique to improve network performance and create meaningful connections among IoT devices. Authors in [11] focused on lightweight virtualisation technologies for IoT devices, deploying integrated applications and creating a distributed and virtualised ecosystem. Authors compared two frameworks for IoT service provisioning: one based on direct interaction between two cooperating devices and one with a manager supervising the operations between cooperating devices forming a cluster. A testbed was implemented, and testing evaluated power and resource consumption. Results showed that lightweight virtualisation allows for execution of a wide range of IoT applications, while enabling the desired abstraction level with advantages in terms of manageability and scalability.

In [12], authors proposed IoT service composition by using a matching value-based method, with the possibility of services being composed by matching IoT services. The work is focused on the representation, discovery, detection, and composition of services. A cluster-based distributed algorithm was also proposed, with a distributed consensus method in order to improve robustness and trustiness of the decision process. Authors have not covered all the phases of service lifecycle.

A wireless sensor network (WSN) deployment architecture was proposed in [13], supporting multiple sinks and layers in order to achieve seamless integration in cloud communication for IoT. An energy efficient routing protocol was also introduced to support multi-layer cluster head selection and transmission to multiple sinks with a load balancing algorithm that considers load fairness index and average residual energy. Tests shows that the algorithm provides significant benefits in terms of network lifetime, however, the proposed work does not support peer-to-peer (P2P) communications.

A clustering algorithm based on load adjustment for IoT in an SDN architecture was presented in [14]. Data-centres and storage units are centralised by an SDN controller which calculates load-balance, communication cost and energy in a clustering algorithm. The authors showed that the proposed algorithm significantly extends battery life of IoT devices and the amount of data sent increases.

C. *Mobility in the Internet of Things*

Several approaches were proposed to address IoT mobility-related challenges. A group-based framework with dedicated path planning for emergency guiding based on IoT was introduced in [15]. The framework models the mobility of indoor people to determine and relieve the congestion of corridors and exits, in order to create the shortest evacuation time for each group of nearby people. A prototype was built to verify the feasibility of the framework, demonstrating that it outperforms existing schemes and can achieve the shortest evacuation time.

Authors proposed an agile data delivery framework for service-based applications in smart cities in [16] with focus on multimedia in WSNs and vehicular networks. The approach finds optimal paths for data packets, while satisfying QoS constraints. The solution was assessed in terms of throughput, energy consumption, and delay. Tests showed decreased average message delay and roadside nodes relaying tasks and increased network's lifetime. Authors have yet to perform tests in a larger network.

A social IoT (S-IOT) architecture and scheme for a group handoff between a mobile access point (AP) to a fixed AP was proposed in [17]. Members in the group can download and share geo-touring information efficiently. A real system was developed using Android and performance was evaluated, with the scheme being able to decrease expense fees, power consumption and service time.

The IoT schemes discussed in this section do not provide mobility support while maintaining good QoS and offering performance-aware clustering during content delivery. Therefore, this paper proposes an innovative scheme that combines mobility and QoS-aware clustering for IoT devices.

III. REMOS-IOT ARCHITECTURE

The proposed solution REMOS-IOT employs an architecture which is composed of clustered IoT objects (things), smart gateways, and the cloud-based IoT Integration Platform (ITINP), as illustrated in figure 2. The next sub-sections describe these components are as well as REMOS-IOT important features such as its *reputation score, utility functions,* and *Object Mobility Support* and *Re-Clustering algorithms*.

A. *REMOS-IOT Main Architectural Components*

IoT objects (such as smart devices, sensors, smart appliances) support one or more services to other objects. The relevance of an IoT object in relation to another object

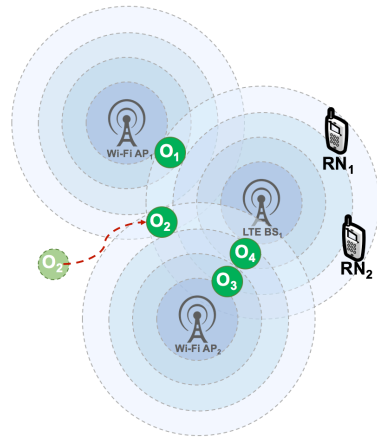

Fig. 3. The REMOS-IOT Mobility Scheme

cluster in a different area, increases with the number of service requests the objects receives from that area. In case of high relevance, the object will be attached to a smart gateway that serves the new area using an available log range wireless connectivity (e.g. LTE). Objects can avail themselves of LTE or WiFi according to their position and the availability, performance and position of the access points or base stations. When attached to a smart gateway (SG_i) or relay node (RN_i), objects receive an ID (O_{ij}) and provide one or more services $S_{ijk,}$ where i indicates the gateway or relay node, j identifies the object and k, the service. Objects are initially connected to the closest smart gateway, forming a distance-defined *physical cluster*.

However, some object services can be requested by many objects from other clusters, and in such cases, these objects are using their current gateway simply as a bridge for communications. A way of preventing this scenario that affects network performance, is regular reassignment of each object to the most relevant smart gateway. If the most relevant smart gateway is at a distant location, a long range wireless network (e.g. LTE) will be used for object-smart gateway communications, forming a logical cluster. An algorithm that supports objects mobility will find the best balance between location and performance, and consider relay nodes (e.g. smartphones or other devices with internet access) for networking devices while they move.

Smart gateways connect IoT objects, manage admission control, aggregate data and store performance-related information in form of reputation scores. Objects can communicate to each other using the smart gateway that is providing them connectivity. If an object needs to access a service provided by an object connected to a different smart gateway, it will reach the object through the cloud-based ITINP, which all smart gateways are connected to. Smart gateways support mobility and are also aware of objects' locations and uses them for admission control and re-clustering of objects. As illustrated in figure 3, the device O_2 moves towards an area with signal from two access points and one base station. ITINP computes the utility function that decides which gateway should reply to the connection request first. For example, device O_4 is closer to BS_1, but depending on its reputation and BS_1 available resources, it could be connected to AP_2 instead.

ITINP is a cloud-based server process responsible for creating and managing optimal clusters of IoT objects, attaching these objects to the best available smart gateway. This is achieved by an algorithm that considers objects' reputations, calculated by a utility function that computes QoS, location and relevance scores (which are provided by the gateways). ITINP is aware of the locations of the smart gateways, therefore, when an object is unable to connect to the most suitable gateway using a short range wireless connection (e.g. WiFi), the object will either be requested to attach itself to the new gateway using a long range wireless technology, or be requested to connect itself to an available relay node with the ability to access ITINP and connect other devices.

B. Reputation Score and Utility Functions

The *reputation score* (U_{ij}) is a combination of the *QoS*, *Relevance* and *Location scores* of REMOS-IOT, and is used for admission and performance control (i.e. re-clustering and re-assigning objects to other smart gateways/relay nodes) and identification of objects with low performance.

The *QoS score* (P_{ij}) associated with every object, introduced in [6] and presented in eq. (1), is obtained by normalising the sum of the normalised values of each metric M_x measured per each service that the object provides. Each gateway maintains this score for objects that have been connected to it. The QoS score of a smart gateway (P_i) is also calculated using this formula. The average of all services of an object, in eq. (2), composes the QoS score of the object.

$$P_{ijk} = \sum \left(\frac{M_x}{\max(M_x)} \right) \; (1) \qquad P_{ij} = avg(P_{ijk}) \; (2)$$

The *Relevance score* (R_{ij}) of an object, defined in [6], is composed of an array of tuples containing each gateway that has communicated with this object and the percentage of total packet communication exchanged between the gateway and object. For instance, a device that has exchanged messages with two smart gateways. This device has sent and received 400 packets from devices in the same gateway (e.g. SG_1) and 600 packets from objects located in a different gateway (e.g. SG_2). The object's relevance score will be R_{ij}={[SG_1, 40%], [SG_2, 60%]}.

The *Location score* (L_{ij}) of an object is determined by its RSSI or Reference Signal Received Power (RSRP) in relation to the reachable gateways.

The overall utility function of the reputation score is presented in eq. (3). REMOS-IOT computed the reputation of an object in relation to a gateway aiming to find a balance between performance, relevance and location of devices, resulting in the normalised U_{ij} score per object. The sum of the weights must be equal 1.

$$U_{ij} = wp\frac{P_{ij}}{\max(P_i)} + wr\frac{R_{ij}}{\max(R_i)} + wl\frac{|L_{ij}|}{\max(|L_i|)} \; (3)$$

The U_{ij} score is used in the re-clustering of low-performing objects (see Algorithm 1). In order to support mobility in objects, the L_{ij} score is used (see Algorithm 2).

C. REMOS-IOT Algorithms

When objects move, REMOS-IOT employs the Object Mobility Support algorithm, which is a handover algorithm adapted from [18] (see Algorithm 1). The algorithm allows gateways to handle movement detection and attachment prediction. Gateways have a threshold of how low the average RSSI or RSRP (L_{ij}) of objects can be (default: -90 dBm), and the algorithm is triggered once the threshold is reached, in order to find another gateway or relay node.

Algorithm 1 – Object Mobility Support Algorithm

if L_{ij} <= *threshold*
  SG_i **broadcasts** message **with** *Object ID* (O_{ij}) **and** L_{ij}
  SG_i **starts** *timer*
  SG_i **waits** other *SGs* **and** *RNs* (that can detect O_{ij}) reply
  O_{ij} **receives** *message* **broadcasted** by SG_i.
  O_{ij} **broadcasts** *message* to *SGs* **and** *RNs*
  SGs **and** *RNs* **compute** L_{ij} **received** from O_{ij}
  SGs **and** *RNs* **send** *message* with L_{ij} **and** U_{ij} *to* SG_i
  SG_i **stops** *timer*
  SG_i **selects** best L_{ij}
  if SG_i **has** best L_{ij}
    end
  else
    SG_i **notifies** *SG/RN* with best L_{ij}
    SG/RN.attach(O_{ij})
    SG_i.detach(O_{ij})

REMOS-IOT also implements the Re-Clustering algorithm (see Algorithm 2) in the cloud-based ITINP. If the object is not in the closest gateway (strongest signal in L_{ij}), then it will be reattached. The relevance and performance of objects in relation to the gateways (computed in U_{ij}) are also considered for re-clustering.

Algorithm 2 – Re-Clustering Low-Performing IoT Objects

Require: P_{ij}, R_{ij}, and L_{ij} per O_{ij} in SG_i
for each O_{ij}
ITINP **computes** U_{ij}
  if SG_i **is not** max L_{ij}
  or SG_i **is not** most relevant *SG*
  and most relevant *SG* P_i >= SG_i P_i
    Most Relevant *SG*.attach(O_{ij})
    SG_i.detach(O_{ij})
  if O_{ij} **has** low U_{ij}
  and most relevant *SG* = SG_i
    Next most relevant *SG*.attach(O_{ij})
    SG_i.detach(O_{ij})

TABLE I
SIMULATION SETUP

Parameter	Value
Simulator	NS-3.24.1
Duration of the Simulation	14s+10s before and after sim.
Initial dist. between nodes and antennas	3 metres
WiFi and LTE Data Rates	40 Mbps and 100 Mbps
WiFi Standard	802.11ac (40MHz, MCS 9)
LTE eNB Antenna Model Type	Isotropic Antenna Model
Remote Station Manager	ConstantRateWifiManager
Mobility Model	ConstantVelocityMobilityModel
Speed of Smart Watch user	2 metres per second
Smart Watch Bit Rate	2 Mbps
Other Devices Bit Rate	20, 10, 4 Mbps and 800 Kbps

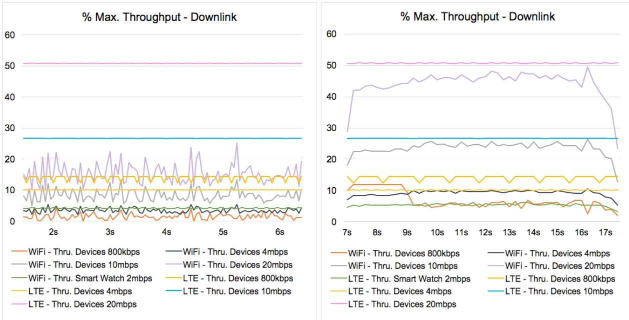

Fig. 4. Max. throughput results for downlink (%)

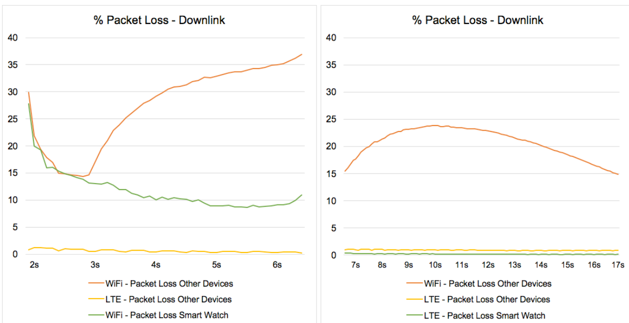

Fig. 5. Packet loss results for downlink (%)

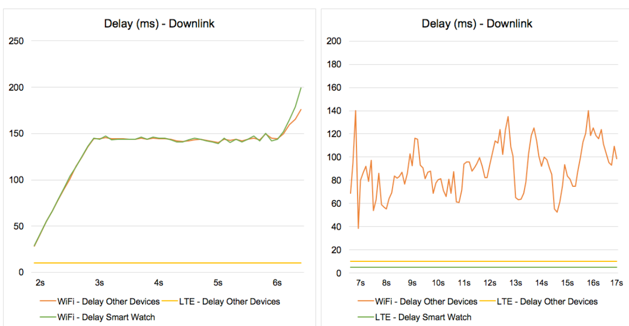

Fig. 6. Delay results for downlink (ms)

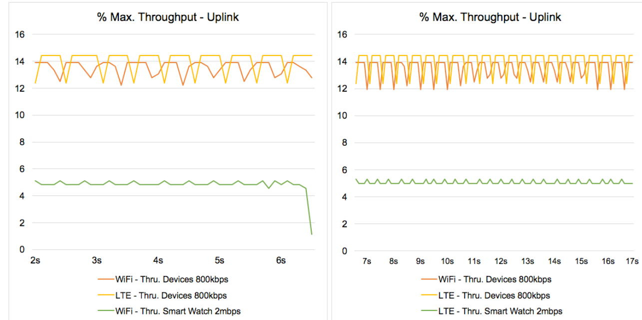

Fig. 7. Max. throughput results for uplink (%)

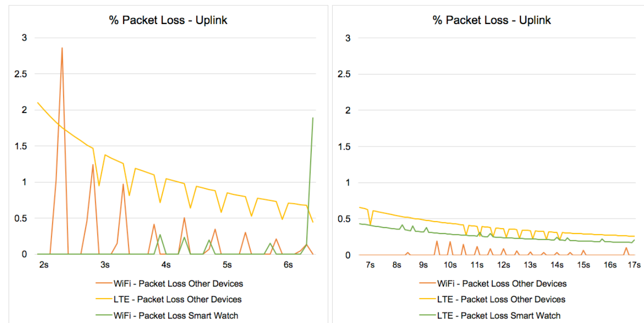

Fig. 8. Packet loss results for uplink (%)

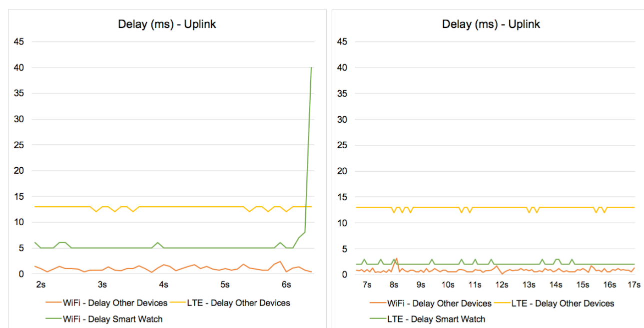

Fig. 9. Delay results for uplink (ms)

IV. Performance Analysis

REMOS-IOT was modelled and evaluated using Network Simulator 3 (NS-3) [19]. Model parameters are presented in Table I. The scenario considered contains a WiFi-only smart watch in a smart house with several other smart devices initially connected to a local gateway using a WiFi 802.11ac access point. Two gateways, connected at WiFi APs support communication for three devices with bitrates of 20, 10 and 4 Mbps, simulating video downlink and seven devices at rates 800 Kbps or lower, representing diverse types of mobile and non-mobile IoT devices. The smart watch, which can stream data at a maximum bit rate of 2 Mbps, moves towards another WLAN. However, while moving, the device is out of the reach of the available WLANs and is connected by a relay node with LTE access. The smart watch moved from one gateway to the other after around 6.5 seconds. REMOS-IOT regularly checks the delivery performance and RSSI of devices, and suggests moving devices that are impacting performance to other gateways in the realm of ITINP to improve the quality of data delivery for all the devices.

Results show that after the deployment of REMOS-IOT, important performance improvements have been observed in terms of throughput, packet loss and delay, the QoS metrics measured in the study. The smart watch and the devices in the LTE base station benefited from REMOS-IOT, while the devices in the WiFi access point did not run any of the proposed algorithms.

The main performance improvements on the downlink are as follows. After the smart watch moved to the relay node and then to the second WLAN, there is a decrease of 11% in average packet loss, almost eliminating it (fig. 5) and average delay decreased from 133ms to 5ms (fig. 6). The other devices in the first WLAN also had gains regarding downlink performance. The average delay decreased from 132ms to 89ms, a gain of 32.5%, average packet loss was reduced to 7%, and as seen in fig. 4, throughput increased in most devices (i.e. the 20 Mbps, 10

TABLE II
BASELINE COMPARISON

	Delay (ms)		Loss (%)	
	IoT - RTP & IoT - RTCP	REMOS-IOT	IoT - RTP & IoT - RTCP	REMOS-IOT
Average	204.74	7.53	2.50	0.43
St. Dev.	2.83	0.11	1.34	0.08
Max. Value	211.00	7.75	5.00	0.60
Min. Value	200.00	7.25	1.00	0.35

Mbps, 4 Mbps devices had throughput increases of 29%, 15%, and 6%, respectively and the seven remaining devices had throughput increases of about 5%).

Regarding the device uplink performance, the smart watch throughput had a small increase of ~2% (fig. 7), while average packet loss (fig. 8) had a slight increase of 0.2%. Average uplink delay (fig. 9) was reduced to 3ms. The other devices have not been impacted much in terms of their average packet loss, delay and throughput, which remained roughly the same. The devices of 20, 10 and 4 Mbps do not have uplink traffic.

We compared our solution against the IoT-RTP and IoT-RTCP Adaptive Protocols for Multimedia Transmission over Internet of Things Environments [20]. The IoT-RTP and IoT-RTCP are adaptive versions of the real-time transport protocol (RTP) and real-time control protocol (RTCP), with a new approach of dividing the large multimedia sessions into simple sessions with awareness of network status, and deployed on NS-2. For the comparison, we averaged the delays and packet losses over time in all devices in the second WLAN, after the algorithms were applied. The results are available in Table II. Our solution outperforms the other schemes with 96.3% lower delay and 82.6% less packet loss on average.

V. CONCLUSIONS AND FUTURE DIRECTIONS

This paper introduced REMOS-IOT, its algorithms and scores for QoS, Relevance and Location. The solution was tested via NS-3 modelling and simulations and results for uplink and downlink were recorded in terms of throughput, packet loss and delay. The proposed solution outperforms other solutions in terms of packet loss and delay.

Future work includes an optimisation of the relevance score by prioritising different types of services and content.

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