TOWARDS 5G REQUIREMENTS: PERFORMANCE EVALUATION OF A SIMULATED WSN USING SDN TECHNOLOGY

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ABSTRACT

The 5G, Fifth Generation of Mobile Networks, currently in its final development stage, promises to innovate the Internet of Things (IoT) ecosystem. It has the potential to aid in problem solving and improve the quality of existing and future services and applications. Some of the main applications include Wireless Sensor Networks (WSN), which may benefit from its very high speed and low latency in communications. Many services and applications related to WSNs are limited due to low speed and high latency connections. Some of its uses in agriculture range from fixed sensors networks for gathering weather data for irrigation control, to mobile WSNs with nodes attached to animals in the field, collecting health and productivity data, among many others. In this paper, we simulated an ad-hoc network with and without Software-Defined Networking (SDN) technology, to verify the average latency and packet delivery rate in conditions to support 5G requirements. To do so, COOJA and it-SDN were used as WSN simulators. It was observed that the use of SDN resulted in similar packet loss rate (1%) and in a considerably lower latency (at least 47%) compared to the other protocols evaluated.

Keywords*:* IoT, Wireless Sensor Networks, 5G; SDN, Autonomous Data Communication Networks

1. INTRODUCTION

The 5G technologies can be applied to many different domains, especially when high speed and low latency are essential. This will improve considerably the adoption of Internet of Things (IoT) technologies (Zanella et al., 2014). This has the potential to change many areas, such as cities, health, industry, and farm production, among many others. 5G is more than just an improvement on current telecommunication technologies Parvez et al. (2018), presenting specific improvements and implementation requirements in comparison to previous technologies.

There are several requirements for implementing 5G technologies in farming operations and processes, but most of the literature focuses mainly on theoretical aspects. Furthermore, as most domains have specific requirements, it is important, when studying the implementation of technologies in a specific domain, to understand what are the adequate requirements and which routing protocol would be the most beneficial to use.

The main objective of our research is to evaluate different routing strategies for an application of Wireless Sensor Network (WSN) on animal production. We used simulation to evaluate the Collection

Tree Protocol (CTP), the IPv6 Routing Protocol for Low-Power and Lossy Networks (RPL), and the Software-Defined Networking (SDN) strategies on a cattle weighting and water consumption scenario, for cattle in pasture, fulfilling 5G and domain requirements.

The main research question we explored is: 'can SDN improve Packet Delivery Rate (PDR) and latency on a WSN application for animal production?' It is important to mention that the same methodology used in this paper can be applied for research in other domains, considering their requirements and adapting the simulation model to better fulfill them.

2. METHODOLOGY

The methodology used in this paper has three main steps:

1. Requirements identification for implementing WSN for cattle weighing on the farm;
2. Requirements identification for implementing 5G in animal production operations;
3. Simulation of the CTP and RPL protocols and the SDN technology, using software COOJA (COntiki Os JAva), a WSN simulator that allows for the simulation of real hardware platforms (Mehmood, 2017).

Table 1 illustrates the parameters of the simulation and the versions of the software used. These simulations will allow the estimation of the latency and PDR of the WSN, with and without SDN, considering different routing strategies.

The protocols used were the following:

- CTP, which is capable of routing data, calculating and maintaining the routes for one or more sinks, focusing on building minimum cost trees. In this case, the sink acts as a root;
- RPL, which builds an acyclic graph, oriented towards a specific destiny, to route the packages.

Table 1. Parameters used in the simulations and software versions

Variable	Attribution	Variable	Attribution
Metrics	Latency and Delivery Rate	MAC Layer	CSMA
Topology	"Grade", Top Left Sink	RDC	NullRDC
TX Range/INT Range	50m/60m	CCR	128Hz
Sucess Rate TX/RX	99%/99%	Radio-Propagation Model	UDGM Distance Loss
Time of each Simulation	12 minutes	PHY Layer	IEEE 802.15.4
Speed of each Simulation	100%	COOJA	v1.8
Nodes Types	Tmote Sky; Statics	Ubuntu	v18.04
Number of Source Nodes	7 or 6 (SDN)	Qt Creator	v5.8
Number of Sink Nodes	1	Instant Contiki	v3.0
Protocols' Utilized	CTP, RPL	it-SDN (Alves et al., 2017)	v0.3

3. REQUIREMENTS FOR 5G TECHNOLOGIES

According to Yousaf et al., 2017, 5G networks represent the next major phase of the telecommunications industry in terms of voice and data communication. Its basic requirements for operation include the entire telecommunications infrastructure (cabling, radio base stations, etc.) and the regulation of frequencies that will be used.

The three main logical requirements that shall characterize a 5G network are based on its ability to support:

1. Enhanced Mobile BroadBand (eMBB) - a scenario in which a high transmission rate and high traffic flow capacity are the main requirements;
2. Massive Machine Type Communications (mMTC) - a scenario that is related to IoT, in which a high density of devices and high energy efficiency are key issues;
3. Ultra Reliable Low Latency Communications (uRLLC) - a scenario in which very low latency (Parvez et al., 2017) and high reliability are the main requirements.

In terms of agribusinesses, we may consider the scenarios of (eMBB, uRLLC) and (uRLLC, mMTC). These entail 5G networks to provide increased peak bit rates at Gbps per user, higher spectrum efficiency, better coverage, and support for a massively increased number of diverse connectable devices. In addition, 5G systems must be cost-efficient, reliable, flexibly deployable, elastic, agile and above all, programmable. The 5G mobile network system is thus going to be multi-tiered and slices need to be deployed and managed at each level, resulting in not only a complex architecture, but also posing big challenges in terms of 5G network, sliced infrastructure, and traffic management. In this regard some of the principal factors are:

1. Seamless and flexible management of physical and virtualized resources across the three tiers;
2. Agile end-to-end service orchestration for each respective service vertical, where each vertical may have multiple service instances;
3. Enabling end-to-end connectivity services to each service instance, which is also programmable.

Considering the above challenges, two key technologies have been developed in order to cater for the scalability, flexibility, agility, and programming requirements of 5G mobile networks: NFV (Network Function Virtualization) and SDN (Yousaf et al., 2017).

4. SOFTWARE-DEFINED NETWORKING - SDN

To provide a flexible and scalable architecture for handling network congestion and complexity in edge-cloud environments, a modern network technology, SDN, has emerged. Within an SDN environment, a single controller or group of controllers may provide data routing control plan services for a greater number of nodes, thus allowing a system-wide view of network resources. The SDN enables data to dynamically be routed on a flow-by-stream basis, using source and destination information, then adapting to possible topology changes, providing better speeds and latency, eliminating potential bottlenecks architectures (Kaur et al., 2018).

The OpenFlow, a protocol that provides an abstraction layer from the physical network to the control element, allows the network to be configured or manipulated through software that works harmonically with SDN technology. Latency is considered to be minimized with a peer-to-peer or distributed SDN controller infrastructure because it shares the communication load of the controller.

Traditional centralized cloud computing has a global view of the network but it is not suitable for applications that require low latency, real-time operation, and high-quality data for Artificial Intelligence services. Edge computing has as its main goal to extend the functions of cloud computing to the edges of the network. Because of its proximity to end users and its decentralized deployment, edge computing can support quality applications and services that present requirements such as real-time execution, low latency, and high mobility with location recognition. This makes it more suitable for applications that generally do not have enough computing and storage resources. By taking these aspects into account, this paper points to a possible new cloud and edge-processing framework, allowing real-time data analysis on IoT networks with SDN.

Communication networks are currently undergoing a major evolutionary change in order to be capable to flexibly serve the needs and requirements of massive numbers of connected users and devices to enable the functioning of the new set of envisioned applications and services in an agile and programmable way. Key terms in that context are IoT, virtualization, software, and cloud-native. In order to be able to maintain and run these networks over 5G slices, SDN technology is widely considered as one key enabler in network architecture (Yousaf et al., 2017).

5. Requirements of WSN for cattle weighing in the farm

The world demand for animal-based food products is predicted to increase by 70% by 2050. Meeting this demand in a way that has a minimal impact on the environment and that improves the quality and performance of livestock farming will require the implementation of advanced technologies.

The use of IoT technologies (ITU-T, 2012) aims at providing full coverage of the processes related to livestock production by collecting and transmitting data along the entire agroecosystem. It should be present on each participant of a livestock chain, bringing and collecting information about their processes, increasing the possibilities for control and improvement on the efficiency of their tasks.

Real-time monitoring of livestock indexes is of special interest to farmers. However, it can become difficult to be evaluated in large herds, especially at grass-fed cattle. For example, beef cattle weighing, in this raising method, is done only a few times during the life-cycle of the animals, due to the difficulty on gathering the animal, or the entire herd together, in a single point, where there is a weighing scale.

Some research developed automated camera-based systems to monitor behavioral activities, diseases, oestrus, as well as individual animal mass (Norton, Berckmans, 2018; Condotta et al., 2018). Although, this technology predominantly is applied for in-house raising methods, in which the animals are confined to a building, making it easier to obtain quality images, or even handle the animals to a weighing scale more frequently.

For that, an automatic weighing system specially designed to open field, grass-fed cattle may bring the aforementioned essential information for the farmer. Using a weighing scale placed close to a cattle drinking through will enable the collection of both the animal's weight and identification tag on a daily basis, meeting the requirements for an automated weighing system on a smart farming environment. Additionally, it becomes easier to monitor water consumption by the herd.

6. Results

Figure 1 illustrates the topology that was used as a base for our simulations. Only the behavior of Mesh 1 was simulated.

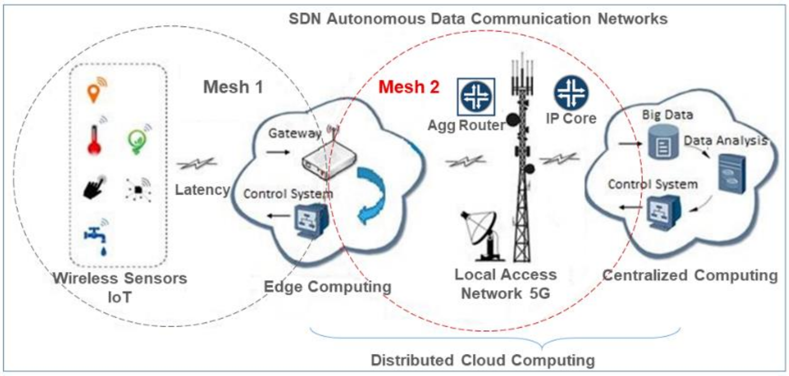

Figure 1. Basic topology of the computational structure and the autonomous network for implementing IoT on 5G. Source: Adapted from Parvez et al., 2017

The topologies used for the simulation on COOJA are illustrated in Figure 2. Figure 3 shows the results obtained under the three simulated scenarios, two of them without SDN (varying the routing protocols) and the last one with SDN.

CTP and RPL protocols, which are capable of generating and maintaining a data routing structure obtained PDRs of 98% and 99%, respectively. With the use of SDN technology, a higher PDR (99%) and a lower latency (56 ms) were obtained compared to CTP and RPL without SDN (132 and 107 ms, respectively), probably due to the centralized control and dynamic behavior of the WSN network.

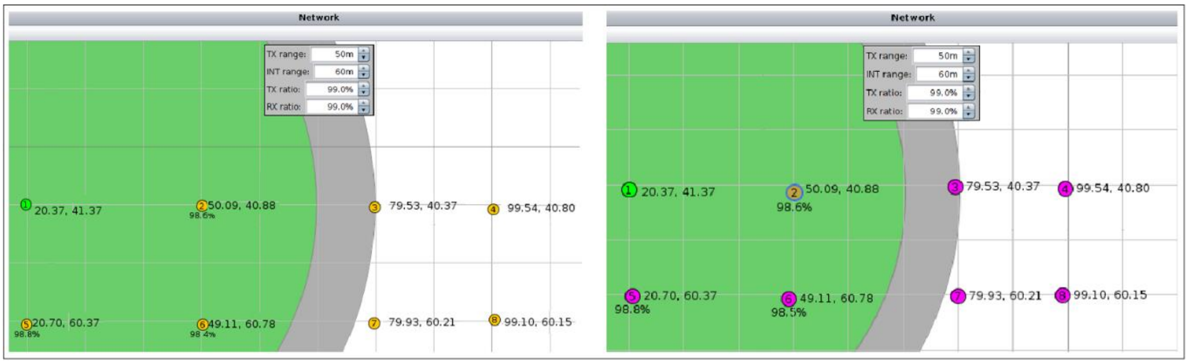

Figure 2. Simulated topologies. a) On the left, the topology without SDN, with node 1 as the sink node; b) on the right, the topology with SDN, with node 1 as the master and node 2 as the sink.

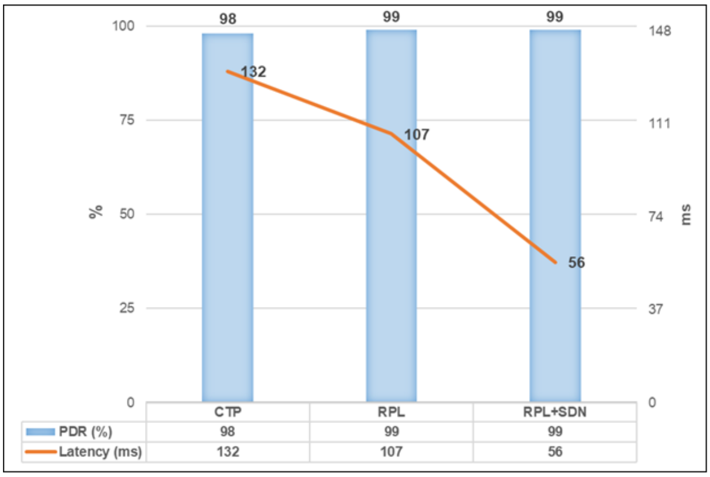

Figure 3. PDR and latency obtained from the 3 different scenarios

7. Discussion

It becomes clear the performance improvement of the RPL protocol over CTP and, especially, with the use of SDN in conjunction with RPL. For networks with mobile nodes, the connectivity should be superior with SDN. Although, we suggest the development of new simulations with mobile nodes.

Data communication networks tend to be autonomous, towards the best 5G performances, as well as the autonomous vehicles of the future, capable of being driven by themselves, without any human intervention (Sandano, 2018). Further, those networks also tend to be worked with Artificial Intelligence under advanced analysis. This requires a coherent combination of intelligence with human control and supervision, software-controlled automated operational processes, and underlying programmable infrastructure so that they can adapt, self-configure, monitor, repair and, optimize by constantly evaluating changes in its own automatic reallocation of resources.

These programmable and autonomous networks will use machine learning and optimization capabilities to adapt dynamically to the service demands and traffic patterns. In this way, software control, will enable the creation and deployment of automated services in autonomous networks, opening new research opportunities for SDN and autonomous networks.

8. Conclusions

There are currently several technical constraints in the models of data communications networks regarding computational rates, cache sizes, communication bandwidths and latencies in front of future Internet traffic volume, which is expected to more than double within the next two years. The IoT networks still suffer from the limitation and capacities of the devices for memory and internal processing, communication protocols, etc. Given the advances in nanoelectronics, there may be a rapid progression in the number of "things" connected to the Internet. On the other hand, the standardization of IoT device data will continue to be a limiting factor for transmission and analysis.

In the simulation done, we achieved a 47% reduction in latency with SDN. For lower latencies, it is necessary to orchestrate cloud computing via software control in autonomous and intelligent networks. The autonomy of the network will not only bring better latency but also other technical-commercial benefits to users and providers. The 5G network orchestration needs to be better studied and standardized due to demands related to low latency, integrality, accuracy, and precision.

Acknowledgments

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