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"VALUE OF INFORMATION ANALYSIS IN THE SMART AGRICULTURE SCENARIO USING WIRELESS INTERNET OF THINGS"

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Value of Information Analysis in the Smart Agriculture Scenario using Wireless Internet of Things

Abstract

The trend of Internet of Things development in the agriculture sector has led a high demand towards advanced technological settings with high efficiency and effectiveness. Often, the constructed sensor network suffers from excessive energy consumption due to the existence of collisions, and/or redundant data transmissions (time and space redundancy). In recent years, researchers have been trying to resolve this phenomenon by introducing a new quantitative metric, named Value of Information, which determines how valuable a generated information is. We want to make sure that the cost we spend for transmitting a packet corresponds to the value of the information that a packet submitted. In this thesis, we analyze such a metric from the agriculture point of view. Practical applications of this rationale include the reduction of update frequency by sensor considering the cost and network models that consider the transmissions of valuable packet only. These problems are evaluated through numerical simulation, in practical implementation contexts of a Lora network in real plantation and from a general perspective of future implementation.

A Short Gratitude Letter

I would like to express my greatest appreciation for those who support me to this day.

I want to say the greatest thank you to my Professor, my Coach, and my Mentor, Leonardo Badia, thanks for giving me a chance and trust me since the beginning. It is not easy, but you keep making me believe in myself that I can graduate from ICT.

I want to say thank you to my parents who finally let me pursue my dream after 5 years of battling, and my siblings Hendarto, Esra and Junjung who always support now dreams come true I am almost graduating.

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The last and the most important I want to say thank you and give the greatest appreciation to myself, for keep going through all those challenges and struggles, for not giving up on her dream, for that determination and the hard work.

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I. INTRODUCTION

1.1. Background

Smart Agriculture has become a trendsetter in the agriculture field, it delivers farming system to be more connected and intelligent. Internet of Things provides a big contribution on this agriculture development; according to Statista and Digiteum, it is estimated that by 2022 there are 75 million IoT systems deployed in agriculture sector. This is supported by the fact of how simple and scalable the application of the internet of things is. We witness how farmers can quickly adapt to this technology and utilize the smart gadgets, which deliver farming operations to become more effective and efficient.

Smart Agriculture expected to give a significant impact specifically in light of the current problems related to the environment. Anthropogenic changes, related to global warming, increase in extreme weather conditions, drying lands, soured soil quality, requires careful monitoring and interventions, thus making efficient usage of natural resources in agriculture a priority [41, 42].

Wireless Sensor Network become one of the best choices, given its simple infrastructure, scalability, and frugality. Wireless Sensor Network basically introduced to enhance the IoT practicality. The architecture usually contained by Wireless Sensor nodes, Gateway Node, Internet, Database Server, and End Users [2]. Data transfer can be done with few different IoT protocols such as Bluetooth, Wi-Fi, LoRa etc.

Many kinds of Wireless Sensor Network model had been developed and implemented in the agricultural field [43-46]. However, there are few issues present such as energy efficiency, routing protocols, determination of optimal deployment strategy [1]. For example, during the temperature or humidity sensing process, often the data from the previous transmission contained by similar information with current transmission data. Also, when it comes to sensor nodes deployment, often the nodes capture the same data simply means we transmit redundant data (spatial redundancy), which cost energy and congestions on the network. But then how do we decide which packet and when to transmit?

Since the IoT implementation in the agricultural sector has growing more and more, the authors believe that it is time to step forward to evaluate how effective and efficient the transmission models that we have built. In 2012 [6] started to initiate discussion on this topic by introducing Age of Information (AoI), age metric that evaluates how fresh the data received, given some data might be stale upon its arrival to the recipient.

AoI is defined as the time elapsed since the latest update received, keeping the AoI as low as possible become crucial to maintain the freshness of the data. We want to make sure receiver station only receiving the fresh and up to date data, meaning by sending frequent packet will reduce the AoI however there is constraint of cost associated by adjusting this method. [6]

derived methods for calculating the age metric and applying queue theoretic methods first come first served (FCFS).

AoI just captures the freshness of the data, but it does not really prevent our network from transmitting worthless data. We require something broader which can assist us to transmitting beneficial information. Value of Information (VoI) then introduced to determine how valuable is an information transmitted by the sensor node. [8] combined AoI and transmission cost considered as their 'VoI', which evaluation comprised on the average node AoI, cost spent for sending updates, and the AoI of neighbor nodes.

As opposed to AoI, Value of Information will decrease over time, staleness will reduce a value of a data, subject to this fact [9] characterized packet and treat based on substantiality value. [9] investigated the Value of Real time Information in Vehicular network scenario in order to prioritize transmission for data that have greatest importance.

1.2. Objective

The goal of this project is we want the Agricultural network to be as efficient as possible, by performing several steps which by the end we try to define the Value of Information (VoI) Formula to be able to distinguish the packet data transmitted by the sender nodes. We agree with [9] that VoI evaluation depends on the node's deployment environment, so each scenario has different object metric. We have done this technical work by deploying LoRa technology end nodes. Lora Technology currently becomes one of the most favorite in the smart agriculture network development as it offers a low power and long-range transmission which suitable for agriculture sector [47].

This thesis analyzes such issues from the perspective of a smart agriculture system, where several circumstances affect the value of information itself, such as cruciality of information, spatial redundancy in which such information has been captured and transmitted by the neighbor node, freshness of data when it arrived in the station receiver, and cost of transmitting the data.

1.3. Outline of The Thesis

This thesis work contains the following parts, Chapter 1 talks about the background of this thesis, what is the objective of the research and how we deliver it. Chapter 2 discuss about the theoretical overview and some related works in the previous, then in Chapter 3 we explain the whole practical and mathematical analysis that we have done on this research work. Chapter 4 will deliver all the results that we have obtained based on what we have done on our works and finally in the Chapter 5 we will give some conclusions and recommendations for the future work based on our result.

II. LITERATURE OVERVIEW

2.1. Internet of Things (IoT)

IoT defined as the network of physical things, which embedded with sensors, software, processing technologies and other technologies that connected and provided with unique identifiers (UIDs) for the purpose of exchanging data with other devices using internet system without requiring human to human or human to computer interaction. IoT systems connect the physical world to the internet, in which it works by attaching the real-world interfaces to the internet [12]. The idea is to allow things connect to Internet for generation of information as well interaction between virtual world and real word simultaneously [30].

There are several views how researchers define IoT, [29] define it as a system of interconnected things which are capable of sensing, actuating, and communicating between themselves and the environments, which also have capability to share and information and act autonomously to the real world and give services without or with human intervention.

IoT which has two keywords ‘Internet’ and ‘Things’, refer to integration of people, processes, and technology to enable remote monitoring, status, manipulation, and evaluation of trends of such devices. It is used in many industries to get more efficient operation, decision making improvement, and increasing the value of business. IoT augment internet with all the fea it has, and with its incorporation Internet becomes a web of people, information, services, and things [12].

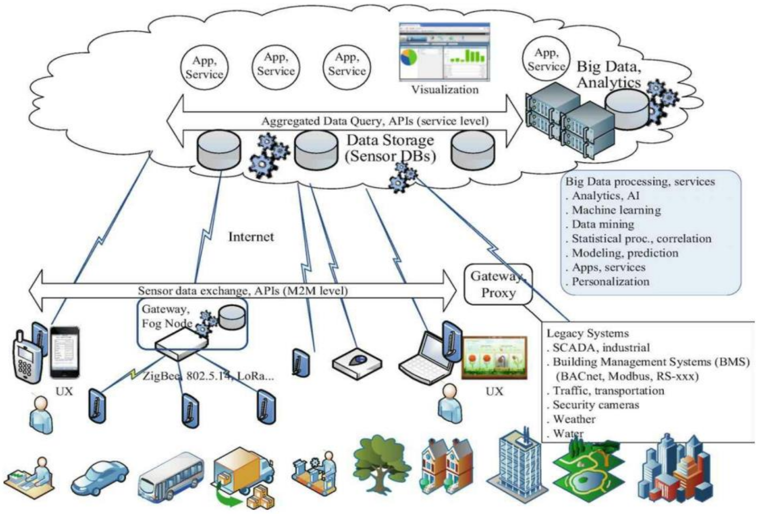


Figure 1. IoT System [12]

There are few fundamental characteristics that IoT system should fulfill as below [31]:

- Interconnectivity

With IoT anything is possible to be interconnected with global Information and communication infrastructure [47].

- Heterogeneity

There are heterogeneous IoT devices on different hardware platforms and networks, which could interact each other or with service platforms in different networks [48].

- Things Related Services

IoT is capable to provide thing related services within the constraint of things, such as privacy protection and semantic consistency between physical things and them associated virtual things.

- Dynamic Changes

The state of devices could change dynamically such as sleeping/ waking up, connected/disconnected, also the context of devices in term of location and speed. Number of devices also could change dynamically.

- Safety

Safety for both creators and recipient of IoT should be designed, including personal data as well as physical wellbeing.

- Connectivity

Connectivity refers to how IoT enables accessibility and compatibility. Accessibility means getting a network on, meanwhile compatibility means providing common ability to consume and produce data.

- Enormous scale

Number of devices which need to be managed or communicate with each other will be at least an order of magnitude larger than devices that currently connected to internet. More important thing will be the data management and their interpretation for application purposes, this related to semantic data also efficient data handling.

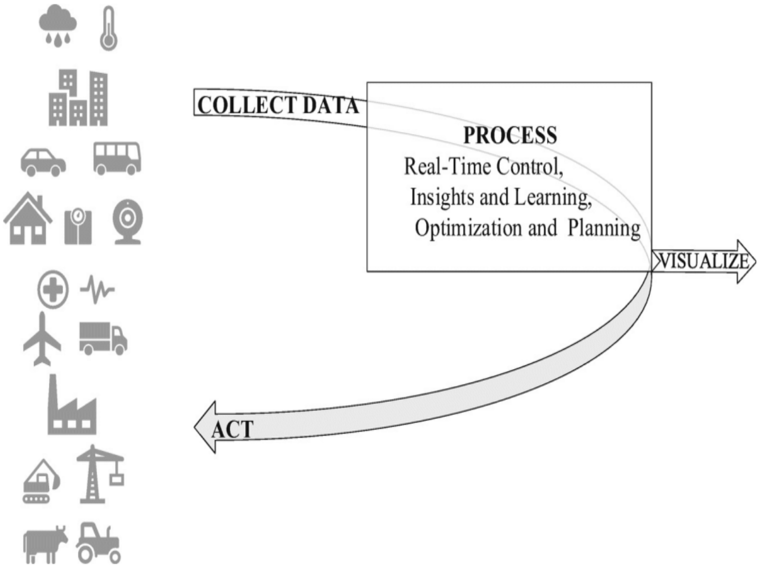


Figure 2. IoT System Functional View [12]

In order to be able to make autonomous system on the IoT infrastructure there are certain steps that processed linearly, Figure 2. shows 3 main stages in IoT data and control flows [49], details as below:

1. Data Collection

This process starts in the edge of infrastructure in which sensors act as the physical interface to monitor and report states of some physical entity's conditions. It may involve several practical works, such as signal conditioning, analog to digital conversion, scaling as well as conversion to engineering units for subsequent processing.

2. Data Processing and Visualization

It ranges from a simple control loop algorithms application for the incoming streaming data until the most sophisticated Artificial Intelligence application which combine of streaming and archiving data, events and records of past condition and observations of the system [52]. Common step may involve filtering, aggregation, and comparison to detect if the sampled data are in special condition. Main phases for this step are [12]:

- Data collection and visualization
- Insights and learning
- Optimizations and actions.

On each of these steps there are several algorithms to be implemented which have been proposed by proven research, i.e. [32] offered data aggregation algorithm based on Geographic Information Awareness and [33] deployed Q-digest (quantile digest) method which each node proceed the received information and creates a message with a fixed dimension.

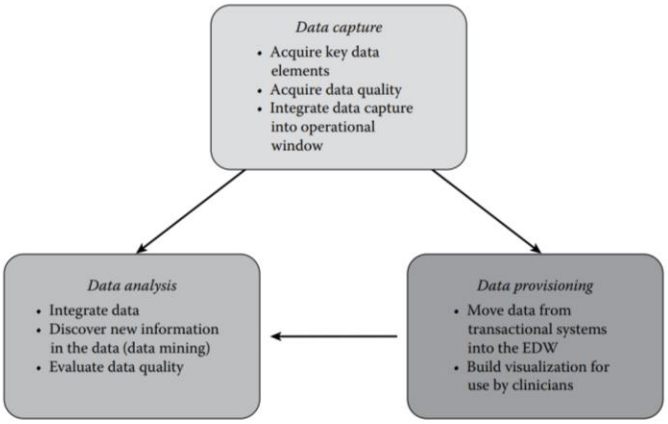


Figure 3. IoT Analytics [15]

3. Action

This step can be done in different forms, from simple remote actuators in response to visualized conditions in a basic monitoring to automatic guidance. Actions implemented in 2 different ways (direct and indirect). This step usually involves human or machine which will execute its specific role in the system, this must be precisely specified with its functional and implementation maps about the exact function and subsystem which are necessary for the task's complete execution [31].

2.2.1. IoT Architecture

IoT architecture consists of different layers of technologies supporting its network, which aims to illustrate how various technologies related to each other and communicate scalability, modularity, and configuration of IoT deployments in different scenarios [29]. There are few important elements in IoT architecture as below:

1. Sensor, Connectivity and Network Layer

This layer consists of RFID (Radio Frequency Identification) tags, sensors which form the essential ‘things’ of an IoT system. Sensors, RFID tags are wireless devices, that form Wireless Sensor Networks (WSN) [49, 51]. This layer contains network connectivity (such as WAN, PAN, etc.), responsible for communicating the raw data to the next layer which is Gateway and Network Layer

a. Smart Device/Sensors

Sensor is device that identifies and reacts to information from the physical situation, these could be temperature, light, heat, pressure, movements, etc. There are few types of sensors based on its functionality:

- Temperature Sensor : this device collects the data of temperature from a source and changes over to a structure that is understandable by another gadget or individual [54].
- IR Sensor : this device identifies infrared radiation which is not noticeable by human eyes [53].
- Ultrasonic Sensor : it is a non-contact type of gadget for gauging separation, it works dependent on the properties of the sound wave, and using the hour trip of it to measure the separation of the item

(Like SONAR).

- Proximity Sensor : it is a non-contact type sensor that distinguish the distance of an item. This sensor can be actualized by using various strategies such as Optical (Infrared or Laser), Lobby impact, Capacitive, and so on.

On the integrated sensor system, it is possible to combine transducer and optional signal conditioning elements with the digital processing logic on the integrated circuit level or by various forms of system in a package (SiP) configuration. With this type of system, they usually produce a digitized outputs which can be communicated by a wired serial buses like I2C or SPI, which goal is to reduce the number of signal traces [12].

b. Actuators

Actuators convert electrical signal into related physical amount such as development, power, sound and so on. It is also classified as a transducer as it transforms one sort of physical amount into another and enacted by low voltage order signal [31].

c. Processor

Processor is the core of IoT framework, it is responsible for managing all control sign to all devices on doing any IoT related activities. For the device registration, processor can be utilized for calculation whereas in implanted framework Micro regulator is utilized [51].

2. Gateway and Network Layer

Gateways responsible for routing the data coming from the sensor, connectivity, and network layer, then pass it to the next layer which is Management Service Layer. This layer requires a large storage capacity for storing large amount of data collected by sensors, RFID tags, etc. [46, 47, 51]. This layer demands a consistently trusted performance in terms of private, public and hybrid networks. As all different IoT devices work on different kinds of network protocols but required to be assimilated into a single layer, this layer takes charge for integrating all these different networks. The network layer which consists of domain nodes, provides encapsulation for the device data and conversion of related protocol to the network layer protocols [29, 31, 32].

a. Gateways

IoT gateways are the physical devices or software programs that serve the connection between cloud and controllers, sensors, and intelligent devices. Basically, it is used to send and receive the data from outside world and providing a place for locally preprocessing that data before sending it to cloud. Although this is seemed important, devices are actually able to communicate without gateways, but then it must be directly over local networks and or over communication network [31]. Overall IoT gateway defined as a network element which coordinates and enables a seamless and full interoperability among the highly heterogeneous devices [30].

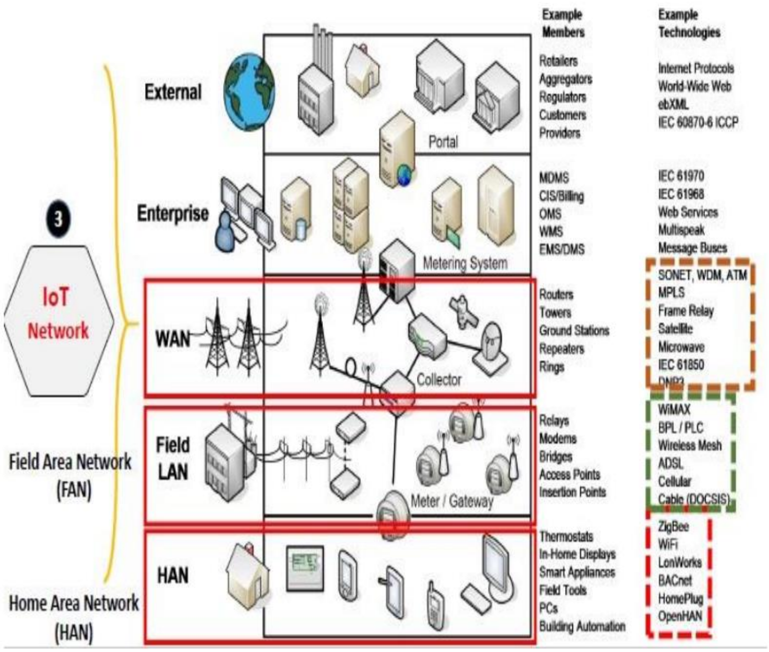


Figure 4. IoT Gateways and Communication

3. Management Service Layer

This layer also known as middleware layer, is responsible for managing IoT services, by securing analysis of IoT devices, analysis of Information (Stream analytics, data analytics), and device management [12]. Data management required for extracting the necessary information from the large amount of data collected to yield a meaningful result. This layer also responsible for data mining, text mining, service analytics, etc. This layer also known to be the core of the Internet of Thing environment, which can be mapped to the application layer in the IP suite (TCP/IP) [29].

4. Application Layer

This is the top layer in the IoT architecture which is responsible for effective utilization of the data collected. Probably the design and development of application layer protocols are the most important reason of the Internet widespread adoption [51]. This has been made available to the developers for transmitting information among the endpoints. There are various IoT applications such as home automation, E-Health [55], E-Government, smart agriculture [3, 42-46] etc.

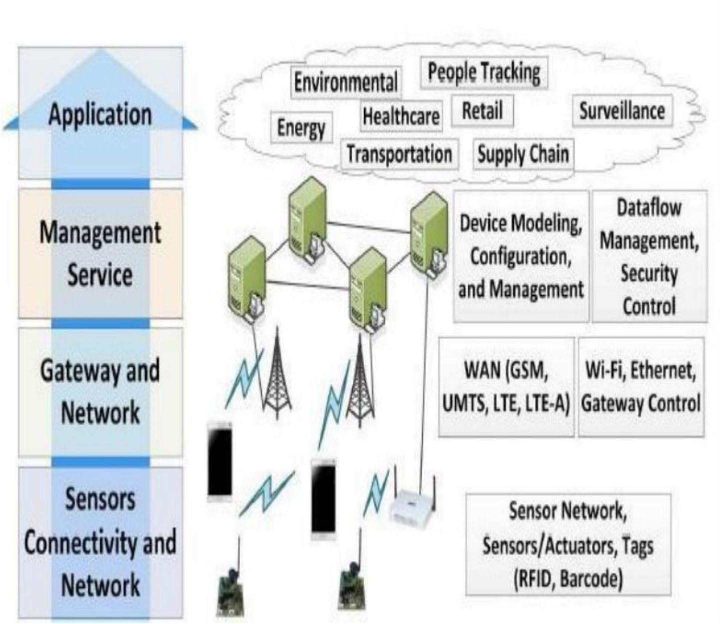


Figure 5. Reference Architecture of IoT

2.2.2. IoT Wireless Technology Standards

The ‘no wires’ installation has made wireless sensor network become an attractive choice for the IoT engineers, as we have known wired sensor installation seemed to be not feasible and complex. Also, the fact that no wires needed makes this system to be less cost and only need simple installation, simpler operation that makes it attractive even for temporary uses. IoT wireless technology often seen as significant to Wireless Sensor Network (WSN). Wireless Sensor Network (WSN) is a network of interconnected sensors powered by the battery and typically developed to serve a specific purpose [4].

These sensors are designed to collect the data from the environment, in agriculture scenario it captures data from the soil or surface ambient, and then will take turn transmitting the data regularly to the station. For the data transmission and interconnection, itself. there are few most common IoT technologies such as Wi-Fi (Wireless Fidelity), Bluetooth, Zigbee, LoRaWan and LPWAN. There are few things to keep in mind for using these technologies such as throughput, energy consumption and capability, different scenario different requirements.

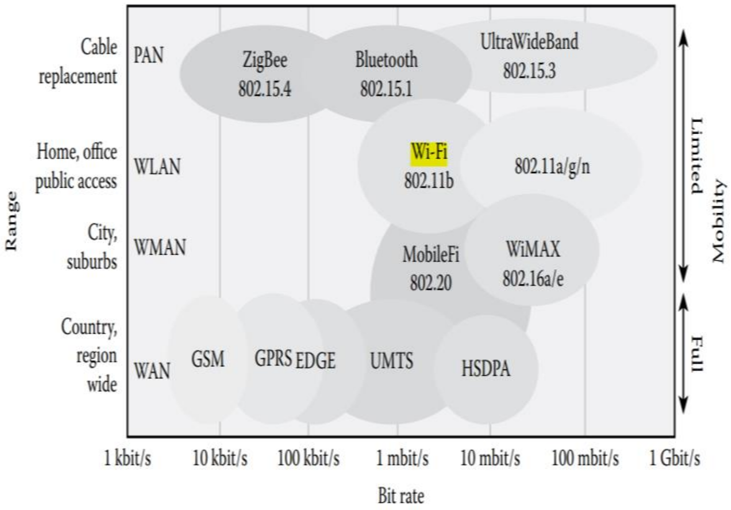


Figure 6. Wireless Communication Standard Systems [15]

A Wireless Sensor Network usually consists of big number of various devices which contain processing capability, power sources such as battery and energy harvesting devices, memory, sensors / actuators, and Radio Frequency (RF) based transceiver [23].

Based on its range there are 3 types of IoT communication protocol as shown in the Figure 7. There are several different IoT standards, they are differ based on its capabilities, limitations, and their basic operations.

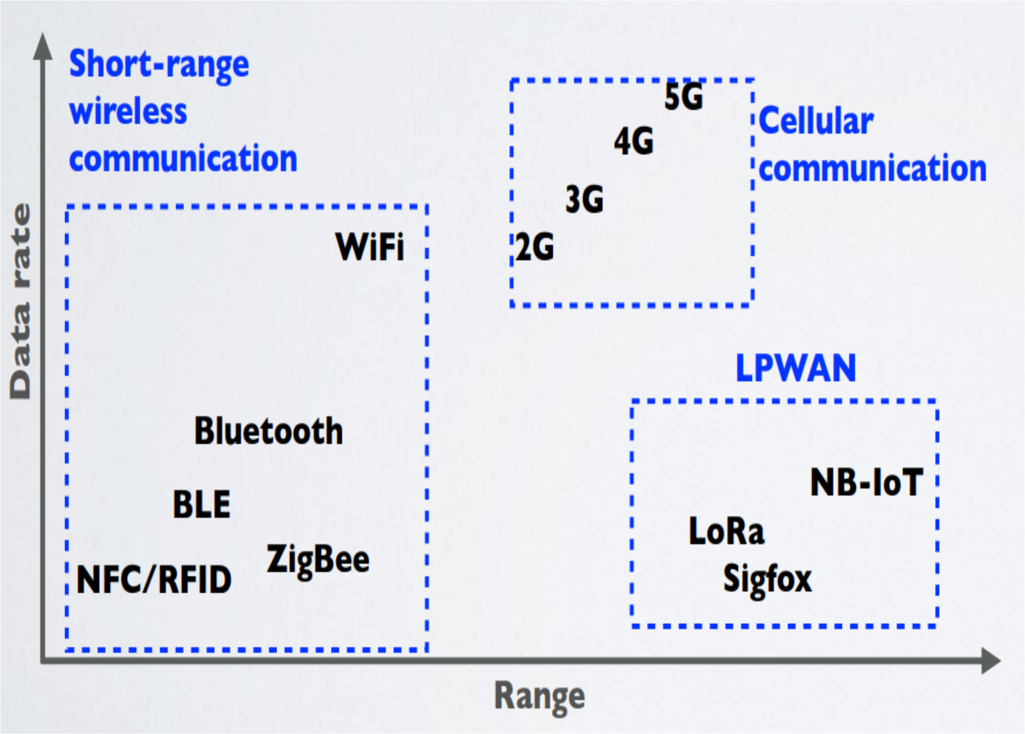


Figure 7. IoT Communication Protocols Based on the Range

Several friendly and feasible options which usually applied in IoT networks are available as follows:

1. IEEE 802.11 Wi-Fi (Wireless Fidelity)

Wi-Fi is well known for its commerciality, it has been using by most electronic devices in the world, from smartphones to numerous smart devices [12]. Wi-Fi has a crucial role in providing high-throughput data transfer for enterprise and home environments.

However, due to its power requirements it only works with bigger and easily recharged devices, indeed not a feasible solution for large networks with battery operated IoT sensors and constrained low power devices [31]. Wi-Fi is designed for short range up to 50 m indoors, and possible longer distance in outdoor environment, the routers offer range until 100 m subject to few conditions (power, interference, environment obstacles).

Institute of Electrical and Electronics Engineers (IEEE) has assigned it with 802.11 standard and operates in either 2.4 GHz or 5 GHz [12], which network operates unlicensed ISM radio frequencies. The main objective is to achieve high data rate which contradictory with power conservation, which making it only suitable for power-affluent nodes within an access point range (AP and WAP), this then to say that it is not suitable for a large area of agricultural scenario.

On this standard and other several IEEE Wireless Local Area Network (WLAN) like IEEE 802.11a and IEEE 802.11g standards Orthogonal Frequency Division Multiplexing (OFDM) applied as the variant of Multi-Carrier Modulation. OFDM modulation technique also applied by IEEE 802.11n and 802.11ac, along with Multiple-Input-Multiple-Output (MIMO).

The speed has increased over time, from 1 Mbps, to 6, 9, 12, 18, 24, 36, 48 and 54 Mbps, the newest Wi-Fi generation, Wi-Fi 6, has brought a greatly enchanted network bandwidth (i.e., <9.6 Gbps) to improve the data throughput [29].

2. Bluetooth

Bluetooth technology (IEEE Standard 802.15.1) has been used in so many different areas. It operates using the unlicensed ISM frequency at 2,4 GHz range same as Wi-Fi, but unlike Wi-Fi this technology is ideal to be embedded in smaller devices [29]. As it is ideal for smaller devices which require less power, it is designed to be used only within a short range 0-100 meters, but commonly used until 10 m range only. The bandwidth ranges started from 1 Mbps to 3 Mbps, with common network topology used are point to point and star topologies, and mesh topology being introduced recently.

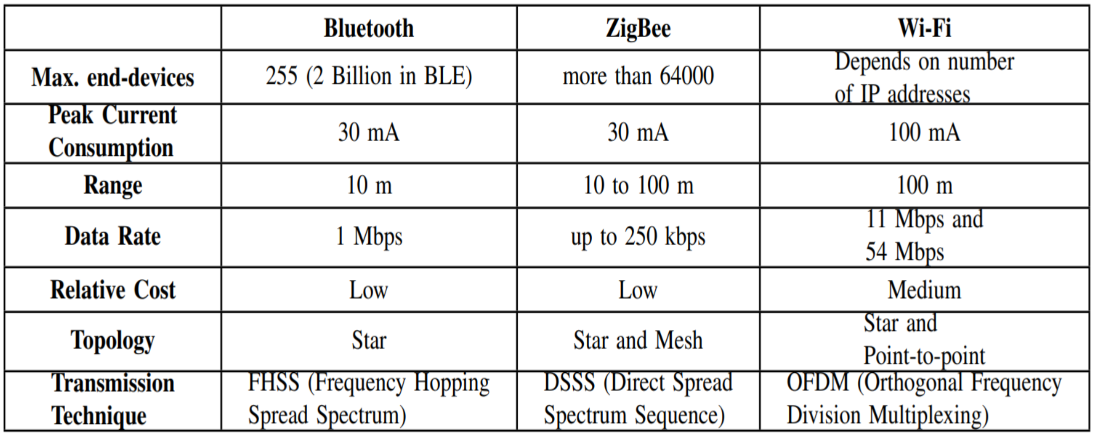
With wireless connection, Bluetooth designed as low power, low cost and short-range node, originally devised to replace wires with radio links. Due to this fact Bluetooth has a significant acceptance in the commercial market, predicted has been installed for over 4 billion devices start from smart home applications until personal devices [31].

A new version of Bluetooth called Bluetooth Low Energy (BLE) has been released in 2011, which requires significantly less power than standard Bluetooth, and offers different bandwidth and range. This version is ideal for periodic transmission of small amounts of data and used in products like connected medical devices and industrial monitoring sensors.

Basically, there are four roles in Bluetooth operations as below [30]:

- Broadcaster : sending advertisement, has a transmitter with receiver as optional
- Observer : receiving advertisement, has receiver with transmitter as optional
- Peripheral : possible to accept connections, and behaves as peripheral (slave) during the connection, has transmitter and receiver
- Central : initiate connection establishment, behaves as master during the connection, has transmitter and receiver.

Table 1. Comparison of Communication Protocol [23]



	Bluetooth	**ZigBee**	**Wi-Fi**
Max. end-devices	255 (2 Billion in BLE)	more than 64000	Depends on number of IP addresses
Peak Current Consumption	30 mA	30 mA	100 mA
Range	10 m	10 to 100 m	100 m
Data Rate	1 Mbps	up to 250 kbps	11 Mbps and 54 Mbps
Relative Cost	Low	Low	Medium
Topology	Star	Star and Mesh	Star and Point-to-point
Transmission Technique	FHSS (Frequency Hopping Spread Spectrum)	DSSS (Direct Spread Spectrum Sequence)	OFDM (Orthogonal Frequency Division Multiplexing)

3. Zigbee

Zigbee is a wireless standard which mostly used for industrial applications, it operates at 2,4 GHz global unlicensed bandwidth (same as Bluetooth and Wi-Fi), it has ability to support 16 channels of 2 MHz band to avoid installations of Wi-Fi. It designed to support proximity devices collection, including battery operated ones which means offer low-cost low power and low data rate network [29]. It uses IEEE 802.15.4 based MAC and PHY layers, which able to build its own network and application layers above them with star or mesh topology configurations [30].

Zigbee has a high scalability as it has 128-bit encryption and offers a high-level security compared to other wireless IoT technologies. Zigbee has a range until 100 meters, it is designed for more limited data exchanges, operating at 250 kbits/second, depends on the environmental characteristics and power output. It also supports Sub GHz in 868 and 915-921 range for international requirements [56].

ZigBee nodes defined with 3 types as below [57]:

- Coordinator (C) : one for each network, no sleep (main power), starts a new PAN and selects its ID and operational channel, it can assist routing data in mesh configurations, and allows R and E devices to join.
- Router (R) : never sleep, support child devices, route the traffic in mesh

configuration, upon its joining to PAN its able to allow R and E devices to join.

- End Device (E) : to reduce the power it has sleeping period, battery powred, and only able to talk with parent nodes R or C, and not able to support child nodes.

It uses Ad hoc On-Demand Distance Vector (AODV) routing protocol, a reactive protocol which determines the route whenever it needs to send a message. The ZigBee application layer provides several flavors of an elaborate framework functions, its mesh configuration has self-healing and reconfiguration ability in the sense that new traffic will bypass failed or disconnected nodes. They support cross-application interoperability by defining profiles, called clusters, of commonly used objects and their properties. Their use facilitates interoperability within ZigBee compliant devices and applications [31].

4. LoRaWan (IEE 802.15.4g)

LoRaWan (Long Range Area-Wide Networks) is built specifically for IoT application on wide area networks specified by LoRa industry alliance [12]. With range up to 20 km, it operates under unlicensed spectrum < 1 GHz on several bands starting from 169 to 430 MHz, 868 MHz (Europe) and 915 MHz (North America). It offers data rates between 0.3 – 27 Kbps [31].

LoRaWan is designed to enable communications with low bit rates and low power wide area networks, which connected to IoT devices with a centralized network server. The payload size is range from 50 bytes to 250 bytes depends on the frequency band, and the bandwidth is up to 50 Kbps, depends on the power and distance. LoRaWan is a network protocol built upon LoRa modulation technique, and its more secure than most of the IoT wireless technologies because it can transmit encrypted data with different frequencies and bitrates that makes it ideal protocol for telemetry uses cases.

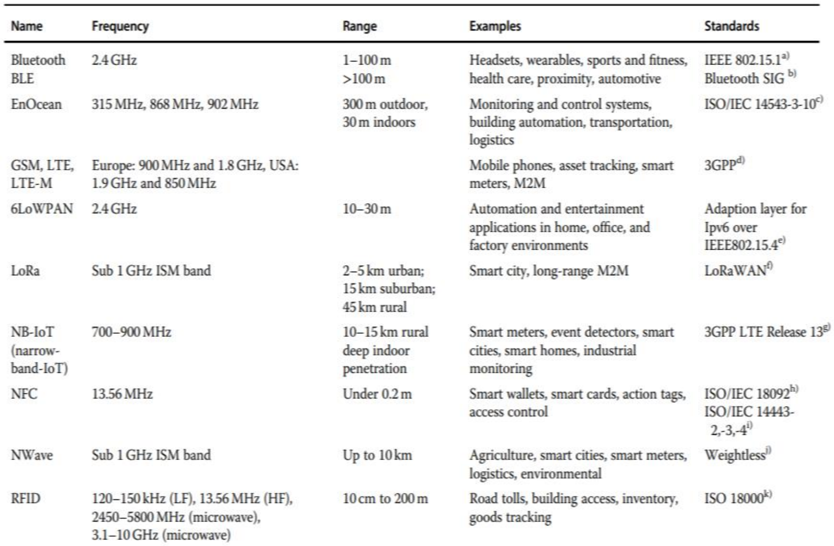
It has been involved in many industrial and smart home applications, it also a key technology for ‘smart city’ [30]. LoRaWan uses the star network topology, in which end nodes have direct link to the radio gateway which located in the center and use it as an intermediary for exchanging the messages with other nodes and connect to LoRaWan servers using a back-end network. A gateway takes charge to support thousands of nodes in which one network can have multiple gateways, to help network reaches better area coverage.

5. OTHER LPWANs (Low Power Wide Area Networks)

LPWAN stands for Low Power Wide Area Networks, it is providing a long-range communication with affordable cost, and small batteries that last for years. It is designed to send small packet data over long distances with low power and data rate [34]. It is built in purpose to support large scale IoT networks sprawling over vast industrial and commercial campuses. They have a huge market in which from overall 30 billion IoT/M2M devices, it is predicted that almost ¼ of them connected to the internet using

LPWAN [23]. It can connect all types of IoT sensors, and facilitate large application such as asset tracking, facility management, consumable monitoring, and environmental monitoring [12]. These abilities make LPWAN to have a big potential in the ‘smart city’ in which it comprised also by smart grids, smart metering, energy radiation measurements, smart parking, etc. [23]. However, as it designed with low power and wide distance, LPWANs can only offer transmission with low rate, so it is more compatible for the cases that don’t need high bandwidth and not time sensitive.

There are several LPWAN networks that provide node interfaces and some parts of the back-end infrastructure, such as Narrowband IoT (NB-IoT), Sigfox and Ingenu [12]. Currently these standards are in process to build infrastructure with Access as a service in different countries to enable low cost offering for the IoT connectivity, in hope it will stimulate many IoT installations which leading to sustainable revenue.



Name	Frequency	Range	Examples	Standards
Bluetooth BLE	2.4 GHz	1–100 m >100 m	Headsets, wearables, sports and fitness, health care, proximity, automotive	IEEE 802.15.1[a] Bluetooth SIG [b]
EnOcean	315 MHz, 868 MHz, 902 MHz	300 m outdoor, 30 m indoors	Monitoring and control systems, building automation, transportation, logistics	ISO/IEC 14543-3-10[c]
GSM, LTE, LTE-M	Europe: 900 MHz and 1.8 GHz, USA: 1.9 GHz and 850 MHz		Mobile phones, asset tracking, smart meters, M2M	3GPP[d]
6LoWPAN	2.4 GHz	10–30 m	Automation and entertainment applications in home, office, and factory environments	Adaption layer for Ipv6 over IEEE802.15.4[e]
LoRa	Sub 1 GHz ISM band	2–5 km urban; 15 km suburban; 45 km rural	Smart city, long-range M2M	LoRaWAN[f]
NB-IoT (narrow-band-IoT)	700–900 MHz	10–15 km rural deep indoor penetration	Smart meters, event detectors, smart cities, smart homes, industrial monitoring	3GPP LTE Release 13[g]
NFC	13.56 MHz	Under 0.2 m	Smart wallets, smart cards, action tags, access control	ISO/IEC 18092[h] ISO/IEC 14443-2,-3,-4[i]
NWave	Sub 1 GHz ISM band	Up to 10 km	Agriculture, smart cities, smart meters, logistics, environmental	Weightless[j]
RFID	120–150 kHz (LF), 13.56 MHz (HF), 2450–5800 MHz (microwave), 3.1–10 GHz (microwave)	10 cm to 200 m	Road tolls, building access, inventory, goods tracking	ISO 18000[k]

Figure 8. Overview of Communication Technologies and Standards for IoT [29]

2.2. LoRa (Long Range) Technology

The Long-Range wireless technology was first developed by a French startup company called ‘Cycleo’, then in 2012 it acquired by Semtech Corporation. LoRa is a part of LPWAN, wireless technology which a low power sender transmits the small packet data to the receiver in long distance. The range can be up to 20 km depends on the environment and geological position [34].

A LoRa Network usually employees of 2 main things:

- LoRa end nodes : usually battery powered and consists of 2 main parts, radio module with antenna and a microprocessor to process the data captured by the sensor. It has a wireless transceiver
- LoRa Gateway : Gateway is connected directly to internet; it is main powered and contains 2 parts, a radio module with antenna and microprocessor.

A gateway can listen to different frequencies simultaneously, in different spreading factor for each frequency. And as LoRa end nodes broadcast the packet data, vice versa multiple gateways also possible to receive from one node. The network is effectively half duplex, that is bidirectional communication means it supports uplink and downlink transmission but in only one direction at a time.

There are 3 types of LoRa nodes [12]:

- Class A (Bidirectional end devices)

  They are low power nodes, and do not support downlink-initiated communication, for each device uplink transmission, it is followed with 2 short downlink windows.
- Class B (Bidirectional end devices with schedule receive slots)

  Similar to class A characteristic with addition that on scheduled times class B devices open extra receive windows.
- Class C (Bidirectional end devices with maximum receive slots)

  They are usually mains-power devices and have the lowest communication latency from server to devices, and it receive windows almost continuously open, it will only close during the transmission.

Lora offers the use of 2 scalable bandwidth: 125 kHz, 250 kHz and 500 kHz, the wider band used means delivering LoRa to be resistant to channel noise, has a fading and long terms frequency because it uses the entire bandwidth channel to broadcast a signal [35]. Vice versa, narrowband signal implementation will make the use of spectrum less efficient until the end devices use different channels or orthogonal sequences which will increase overall system capacity.

There are some constraints needed to be kept in mind when setting up LoRa networks as below [31, 34]:

- **Packet Structure**

LoRa technology offers a maximum 256 bytes packet size, which usually composed by [35]:

- Preamble field, used by receiver on the synchronization process of the incoming data.
- Header field, there are to available operation modes, in the default explicit mode the number of header field defines FEC code rate, length of payload and CRC. In the second implicit mode, coding rate and payload are fixed in the frame, as frame doesn't contain this field, so it gives lower transmission time. It also has 2 bytes CRC that allows receiver to discard packet with invalid header. Header field include the CRC field are 4 bytes long which encoded in ½ CR.
- Payload field, the size varied from 2 until 255 bytes. It contained by:
  - MAC Header to define the type of frame (data or ACK), protocol version, and direction.
  - MAC payload, for the real data.
  - CRC contains cyclic redundancy check (CRC) for error.

- **ISM Band**

When using 863-870 MHz ISM band in Europe the users need to follow some rules as below [30]:

- Maximum transmission power for uplink: 25 mW (14 dBm)
- Maximum transmission power for downlink (869,5 MHz): 0.5 W (27 dBm)

- **Time on Air (ToA)**

ToA is the amount of time elapsed for the transmitter antenna transmitting data to receiver antenna. It increases along with the payload size and SF value increment, and also varied by the change of coding rate. ToA also affected by the change of bandwidth, higher bandwidth decreases the ToA value as it gives transmission opportunity to utilize higher band. ToA defined as below [34]

$$Tpacket = T\ preamble + T\ payload$$

- **Duty cycle**

Duty cycle is the proportion of time for a component, device and system operating, which expressed in ratio or percentage. Devices which connected to a LoRa might sleep for long period to reduce energy and unable to communicate [30]. Duty cycle per day can be 0.1% and 1.0 % depends on the channel.

During the network set up our goal has always been to set the most effective and efficient network. These different parameters define the characteristic of LoRa modulation:

1. **Coding Rate**

Lora modulation implementation added Forward Error Correction (FEC) by encoding 4 bits data with redundant to 5-bit, 6-bit, 7-bit or 8-bit, this FEC is used to increase the receiver sensitivity [23]. On its operation, LoRa offers Coding Rate value from 0 to 4, CR = 0 means there is no FEC. Higher redundant means more robust to intervention, so if the transmission area has many obstacles, it is better to set up higher coding rate, although its then will increase time on air. In this case we use 4/8 coding rate [35]. However, the higher CR value, the effective data rate is decreasing in each bandwidth [23].

2. Spreading Factor

Spreading factor is ratio between the symbol rate and chirp rate. On its modulation, LoRa offers multiple orthogonal spreading factor started from 7 until 12 [34]. SF Impact the time on air of the packet and provides a tradeoff between the range it covers and data rate. Higher spreading factor can increase the range but also it increases time on air and Signal to Noise Ratio (SNR) and decreasing the data rate. Transmission time defined by the Spreading Factor and Bandwidth.

$$\mathrm{Ts} = \frac{2^{\mathrm{SF}}}{\mathrm{BW}}$$

On its modulation, Spreading Factor must be notified at the receiver to make the successful transmission. Substitution of a symbol to multiple chips of information simply defines that the spreading factor directly influence the data rate [23].

3. Bandwidth

Bandwidth is the width of frequency used to modulate the signal in the transmission band, bandwidth also represents the chip rate from the LoRa signal modulation, typical LoRa network operates at either 500 kHz, 250 kHz, and 125 kHz which for Europe area only 125 kHz and 250 kHz are allowed [29]. Higher bandwidth means higher data rate (shorter time on air), but lower sensitivity and vice versa. The spread data transmitted by the sender in a chip rate equal to the system bandwidth in chips per second per Hertz. That is to say on 250 kHz of bandwidth, LoRa corresponds to 250 kcps [23].

4. Transmission Power

Transmission on LoRa can be adjusted from -4 dBm to 20 dBm, due to hardware implementation limits the range is often limited to 2 dBm to 20 dBm.

2.3. Age of Information (AoI)

The concept of Age of Information (AoI) was firstly introduced by [16] in 2011 to identify the freshness of a packet data captured by the receiver station, defined as the time elapsed since the last successful message received. This new metric has helped to quantify the freshness of data at any moment from the receiver point of view as receiver always wants to have the data as fresh as possible. It has attracted a high interest among the researchers based on two factors, first is the sheer novelty brought by AoI in characterizing the freshness of information, the second is based on the need of characterizing the freshness of such information carried by a packet data which is crucial in a wide range communication, information, and control system [13].

With this metric we then can define how up to date is a data given some transmitted data might became stale after the certain transmission period. As an end-to-end metric, Age of

Information can be used to characterize updating system status and application latency [14]. Let's say there is an update which timestamp is u at time t, so we can define the Age of Information as:

$$\Delta_i = t - u$$

In which t defined as the time when a packet arrived, $t \geq u$, with this equation we can conclude that the freshest information has AoI = 0, when the timestamp is equal to the current time [14]. The AoI will directly dropped to zero as soon as the new packet data received, that's why the scheme of how AoI evolutes is shown as below:

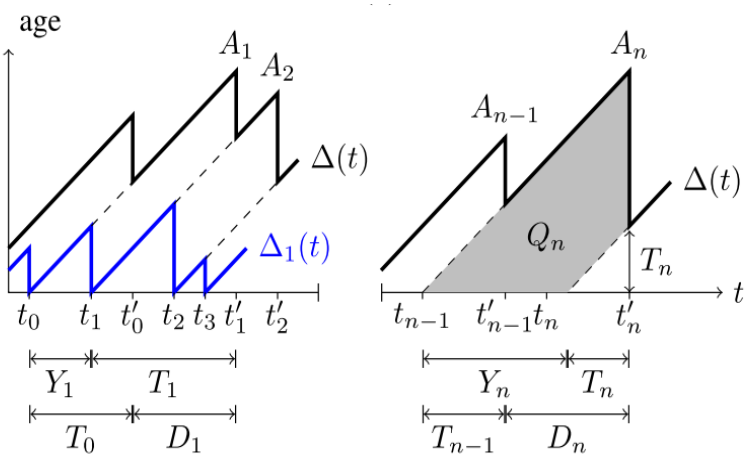
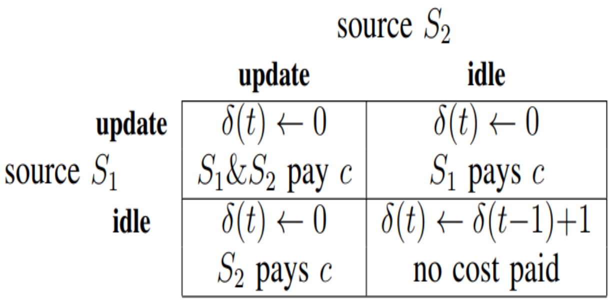


Figure 9. Evolution of Information age [14]

The fresh updates are released at time t_1, t_2, ….. , t_n and we can see $\Delta_1(t)$ as the most recent update Age of Information monitored in the input network which will keep growing until the next packet released [14]. These updates then arrived in the destination monitor at time t_1', t_2',…., t_n' which will obtain the AoI at time t_1' on receiver monitor as $\Delta_1(t') = t'_1 - t'$. Age processes of $\Delta_1(t')$ and $\Delta_1(t)$ have the sawtooth pattern characteristic, other monitor in the network also will have an age process resembling when it receives update [14].

By the years research then started to give attention to this novel metric, [17] has brought an interesting insight by investigating a system with 2 nodes, and both being able to decide either to update data or not by game theoretical approach. It shows 3 Nash Equilibria with different efficiencies and shows that the idea of using 2 both sources doesn't result an efficient equilibrium.



		source S_2	
		update	**idle**
source S_1	**update**	$\delta(t) \leftarrow 0$ $S_1\&S_2$ pay c	$\delta(t) \leftarrow 0$ S_1 pays c
	idle	$\delta(t) \leftarrow 0$ S_2 pays c	$\delta(t) \leftarrow \delta(t-1)+1$ no cost paid

Figure 10. Decisions' Outcome Scheme Offered by [17]

The system has done as follow, the node which decides to send data is necessary to pay a certain cost and gets a benefit which decreases its Age of Information. We have applied this idea on our work by letting the node decides to send or not similar to this approach.

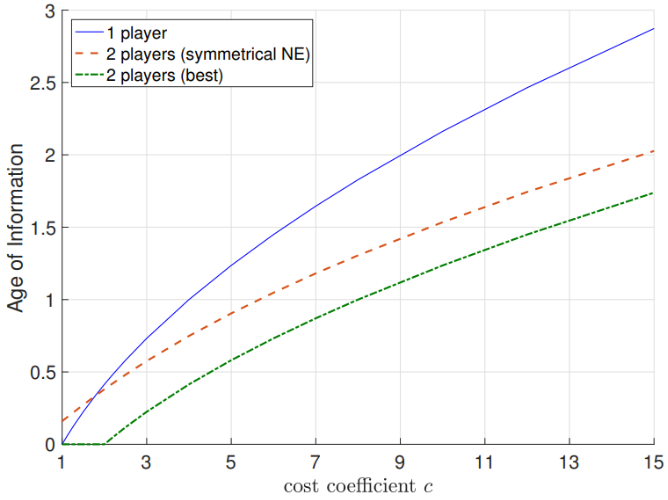
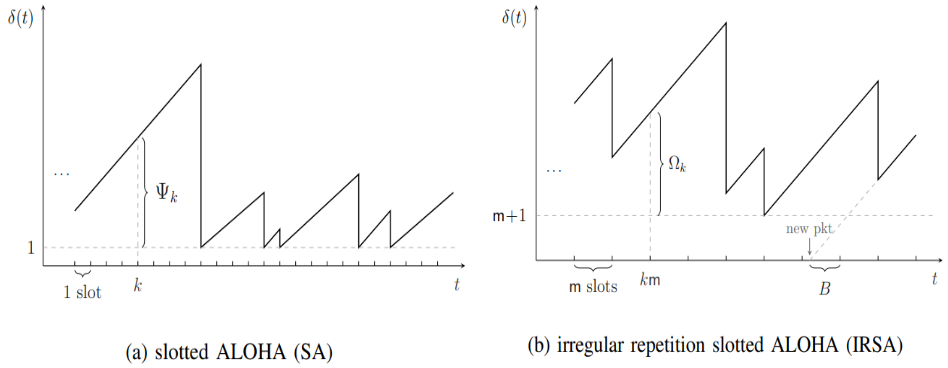


Figure 11. Expected AoI as a Function of Transmission Cost for Different NEs [17]

[36] developed scenario with a large number of devices with a share wireless channel in uncoordinated fashion and studied the Age of Information by deploying Irregular Repetition Slotted ALOHA (IRSA) protocol. Using Markov Chain analysis they prove that the process is ergodic and obtain a compact closed form expression for its stationary distribution. They highlighted a remarkable potential for modern random access for the information freshness point of view.



(a) slotted ALOHA (SA)

(b) irregular repetition slotted ALOHA (IRSA)

Figure 12. Comparison of AoI Evolution with Regular and Irregular Slotted Aloha

2.4. Value of Information

AoI has been thought as one of the most brilliant ideas in the network efficiency solution. As the research expanded to broader evaluation, the idea of the usefulness of data transmitted then started to take some attention in the research field. Given that the traditional approach only captures the freshness of data means it does not really prevent network from sending redundant or even useless information.

It becomes essential to assess the Value of Information, which are provided by the data sources to prioritize packet that have greatest importance for the target applications. The term of Value of Information started to be introduced [24, 26] for reducing data transmission to maximize the utility for target application [11]. This metric has been applied for military operation for prioritizing the information to send during the war to the soldiers.

It also has been investigated on IoT applications and underwater system network. [11] propose a method for assessing the VoI and rank scheduling options for the deployed nodes. On their framework [11] tried to exploit analytical hierarchy decision processes (AHP) for quantifying the expected value of information based on space, time, and quality dependencies, which results also included on the impact of the propagation scenario, type of the observation and communication distance.

[37] have done investigation in Underwater Wireless Sensor Networks (UWSNs) for submarine surveillance and monitoring. Their goal is to maximize the VoI of the data

delivered to the sink by deploying an Integer Linear Programming (ILP) model for path planning and Greedy and Adaptive AUV Path finding (GAAP) to drive the AUV to collect packets from nodes. The result shows that GAAP method delivers more than 80% of the theoretical maximum VoI delivered by the ILP model.

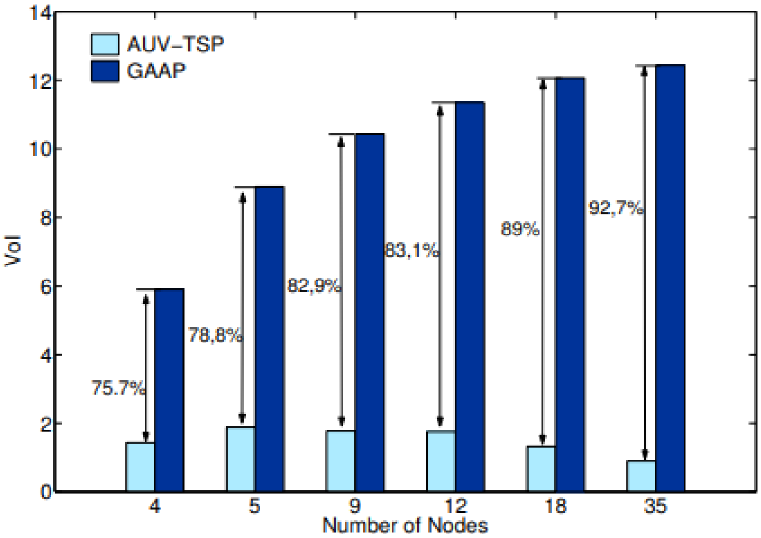


Figure 13. GAAP vs TSP like Heuristic [37]

Another interesting research has been done in [8] in which the authors built a model in remote sensing scenario. On this journal the authors showed how the neighbor’s existence and its correlated captured data can impact the value of data captured by sensor interest. The authors have the analysis by applying a 2-dimensional Markov Chain, in which the VoI evaluations comprised by AoI of sensor interest, cost spent and the neighbor’s AoI.

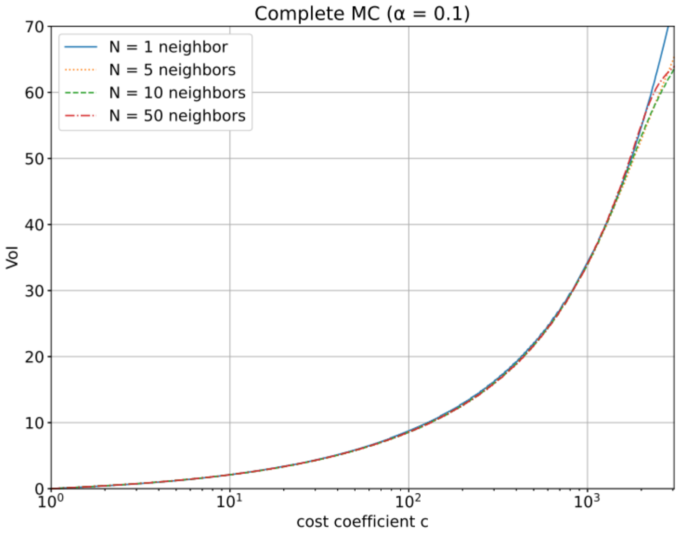


Figure 14. VoI of the complete MC with α = 0.1 vs. the cost coefficient c [8]

III. METHODS

3.1. Setting Up LoRa Network in the Vineyard field

We have done practical observation based on the internship that has been done in Vineyard Online Srl, in the vineyard area located in Agripolis, Legnaro. With the field area of 80 m x 130 m, we want to deploy end nodes in 3 different positions as showed in figure 9, these nodes then capture each point's condition and take turn to send data to Receiver/Gateway every hour. So, we try to do simulation with network scheme shown as figure 9.

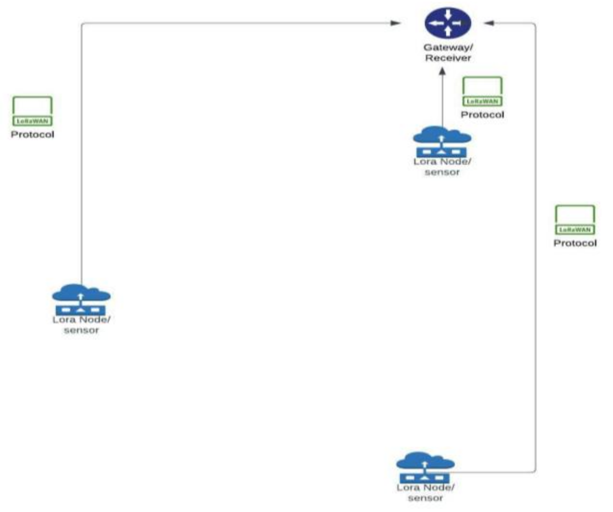


Figure 15. Simple LoRa Network Scheme

As part of this thesis activity, we have deployed Heltec Cube Cell HTCC AB-01 as the end nodes which specification as below:

- Arduino compatible
- 3.5 uA in deep sleep
- Compatible with Solar Panel

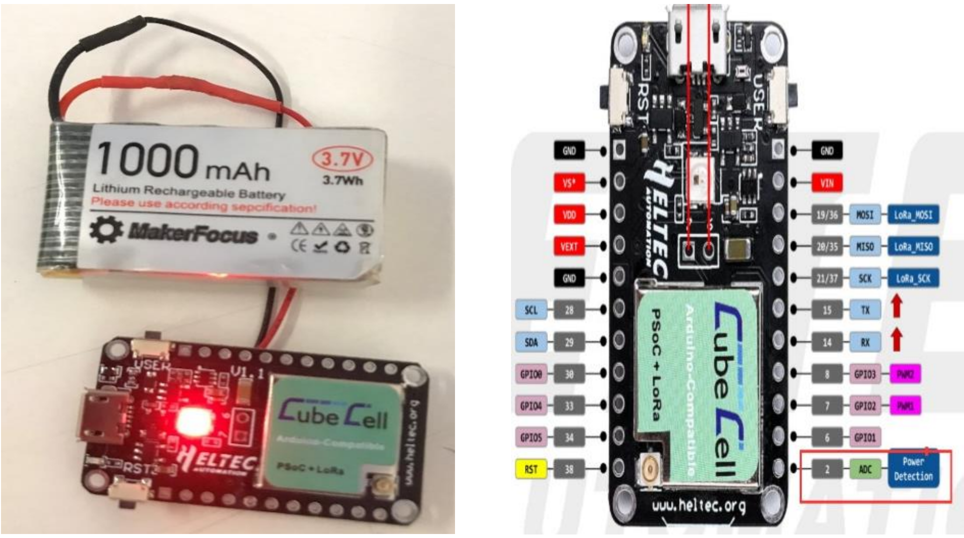


Figure 16. Heltec Cubecell HTCC AB01

Most of the time, large agriculture areas usually located in the remote area, so we need a high coverage network with low battery power installation. LoRaWan seems to best choice given all advantages it offers, so on this practical work we have deployed LoRaWan Standard for our data transmission. With this technology, data transmitted with longer range than Wi-Fi, Bluetooth or Zigbee, up to 20 km.

It's capability to enable communication with low bitrates and low power makes LoRa fits for sensors and actuators operated in low power mode. LoRaWan operates under unlicensed spectrum < 1 GHz and it offers data rates between 0.3-0.5 kbps. LoRaWan also seen to be more secure than other IoT wireless technologies, due to its capability to transmit encrypted data with different frequencies and bitrates.

Figure 17. Sensor Deployment

LoRa modulation transmits the data over a license-free megahertz radio frequency bands: 169 MHz, 433 MHz (Asia), 915 MHz (North America) and the bandwidth 868 MHz allocated as frequency bandwidth in Europe area. LoRa enables the very long transmission even until 10 miles in rural area. This can be obtained by setting up the proper narrow bandwidth and parameters set up.

Next step we will deploy different parameters to find the best set up for our environment. For this network sensor simulation, we have employed the Arduino IDE software tools to upload the program on our end nodes.

```

#include "LoRaWan_APP.h"
#include "Arduino.h"

/*
 * set LoraWan_RGB to 1,the RGB active in loraWan
 * RGB red means sending;
 * RGB green means received done;
 */
#ifndef LoraWan_RGB
#define LoraWan_RGB 0
#endif

#define RF_FREQUENCY                                868000000 // Hz

#define TX_OUTPUT_POWER                             14        // dBm

#define LORA_BANDWIDTH                              1         // [0: 125 kHz,
                                                              //  1: 250 kHz,
                                                              //  2: 500 kHz,
                                                              //  3: Reserved]
```

Figure 18. Arduino IDE Interface

IDE stands for Integrated Development Environment, it is an official open-source software introduced by Arduino.cc, its mainly used to build codes, edit, compile, and upload a program which called ‘sketches’ to the microcontrollers [21]. IDE environment basically contains of 2 basic parts:

- Editor : used for writing the code and program
- Compiler : used for compiling and uploading the code to the microcontroller

Arduino IDE environment supports both C and C++ languages, which is easily available for different operating systems such as Windows, MAC, Linux, and Java Platform which comes with inbuilt functions [20].

Setting up LoRa transceiver network meaning we need to keep in mind the data rate and coverage area we expect on our network, this is obtained by how appropriate we set up the parameters. Given that in our area and most of scenarios there are a lot of obstacles such as trees, buildings, and due to Geospatial location, we want to make sure that our signal will be robust enough to transmit data with long range. LoRa can be configured in different transmission parameters such as transmission power, Spreading factor (SF), Bandwidth and Coding rate. On their research [10] tried to tune link performance and energy consumption.

The first objective is just to find best parameters set up to transmit data as furthest as possible, so we tried to deploy different set up. Below are parameters we found that have implemented so far based on the practical situation:

- Transmission Power : On this experiment they have decided to set TP 14 dBm for all treatments as power levels higher than 17 dBm can only be used on a 1% duty cycle [10].
- Spreading Factor : After several simulation we found that SF 12 is the most suitable on our requirement as it can transmit data 100% compared to lower spreading factor.

We want the receiver to be able to get the updates even with many obstacles, this effects our transmission rate, but the first step consideration is there is no need of real time update as our focus is to get as large as possible transmission distance. Higher spreading factor correlated with higher processing gain (robustness), higher transmission distance. Higher SF needed when the signal is weak and many obstacles around.

- Bandwidth : Bandwidth setups comply the transmission environment, since the considerations are the needs of higher coverage area so means stronger sensitivity we choose to set up the bandwidth to 125 kHz.
- Coding Rate : Higher redundant means more robust to intervention, so if the transmission area has many obstacles, it is better to set up higher coding rate, although its then will increase time on air. In this case we use 4/8 coding rate.

On this observation we also have set up the receiver in the Legnaro campus university of Padua which located around 2 km from the vineyard with 10 meters altitude, there are many obstacles around the area, so it is important to keep the robust transmission power. However, this then contradicted with the time on air that we get for the transmission, we have used LoRa calculator [13] to find the time on air using these scenarios that we have built as below:

Table 2. Practical Parameters Set Up

SF	CR	Bandwidth (kHz)	Payload (bytes)	ToA (ms)
12	4 (4/8)	125	32	2,498.56

With this scenario the duty cycle will be one message every 04:10 (mm:ss). In Europe area duty cycle is limited to 1% which means the total allowed uplink Time on Air is 864 sec per day, with the scenario of every hour transmission per node which means we will do 24 times transmission per day, so it said we take 60 sec per node per day Time on Air. This may seem a good idea to keep the data robust but at the same time there is a cost in which we will have to minimize the bit rate and payload size frame. We then compare this situation based on mathematical and theoretical point of view as will be explained in the next step.

3.2. Offered Parameters Set Up Based on Theoretical Analysis

Next, we want to evaluate our network with respect to energy efficiency and Value of Information, we want our network to transmit as quick as possible, means we want parameter's set up that does not spend too much time on transmission (lowest Time on Air). We have simulated transmission with different parameters set up and below are the sets with lowest Time on Air:

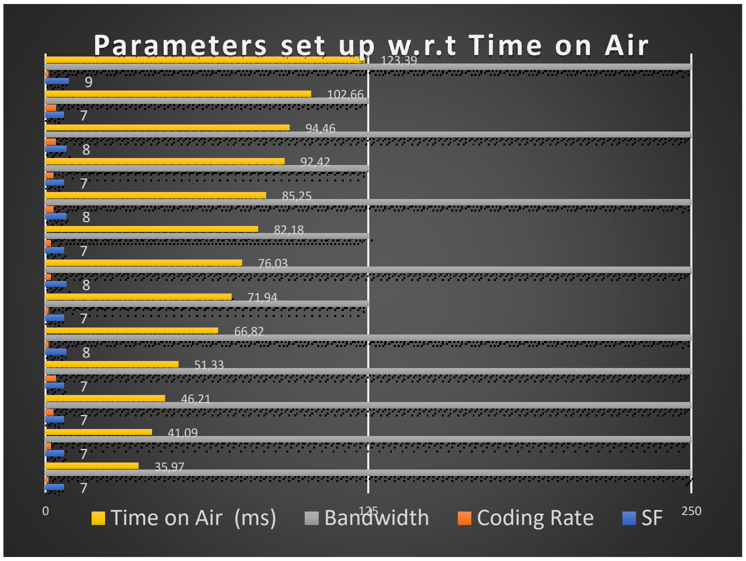


Figure 19. Parameters set up with lowest time on air

As what we have seen in the graph the lowest Time on Air values are offered in Spreading Factor 7 and Bandwidth 250 kHz. On Figure. 20, we plot Time on Air with this set up in different Coding Rate:

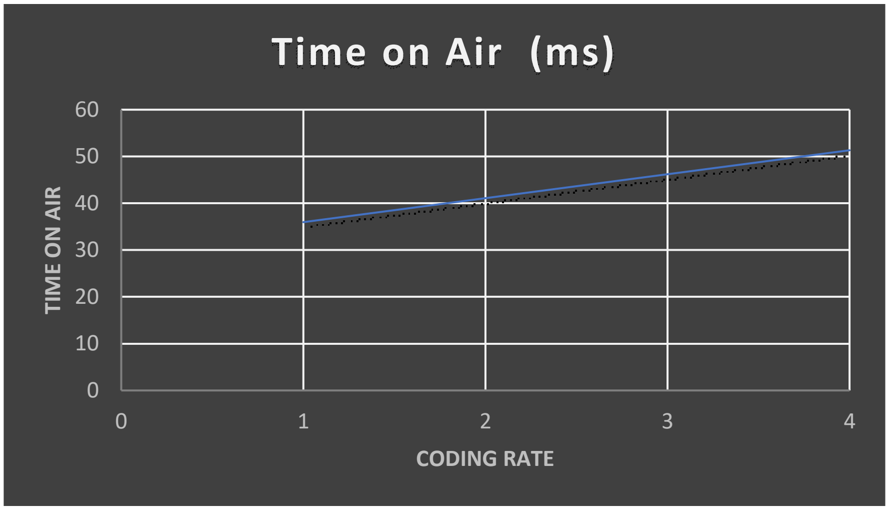


Figure 20. Time on Air vs Coding Rate with SF 07 and Bandwidth 250 kHz

As we can see from the picture, higher coding implying for a higher Time on Air, but this must be decided through our environment scenario, as when the field area is comprised by a lot of obstacles then it means we will have to use the highest Coding Rate, because at the end the first objective is always to make transmission successful.

As we deploy multiple end nodes there is another problem that might constraint our network from transmitting data as effective as possible, data collision. Despite of its strength and ability there is one challenging issue in LoRa transmission regarding the collision detection. LoRa MAC layer, LoRaWan simply employs the system like Aloha, transmitting the packet whenever it has something to send without monitoring the station availability which cause collision.

LoRa itself doesn’t have a collision prevention such as OFDMA or CSMA/CA, and it requires a complex work to implement since they are uplink-networks. So, when multiple nodes transmitting the packets on the same time, the receiver will only be able to receive packet from the strongest signal. We applied a simple approach to give some slots to the end nodes, so each node will have its own time slot to transmit its data.

We then compare the result using basic LoRa protocol Aloha (random sending) and slotting method. During the random transmission without any protocol set up the receiver only able to receive packet from one node which has the strongest signal which in fact in this case we give same treatments to all nodes. Meanwhile we give some slots which result each node successfully transmit all its data by each node.

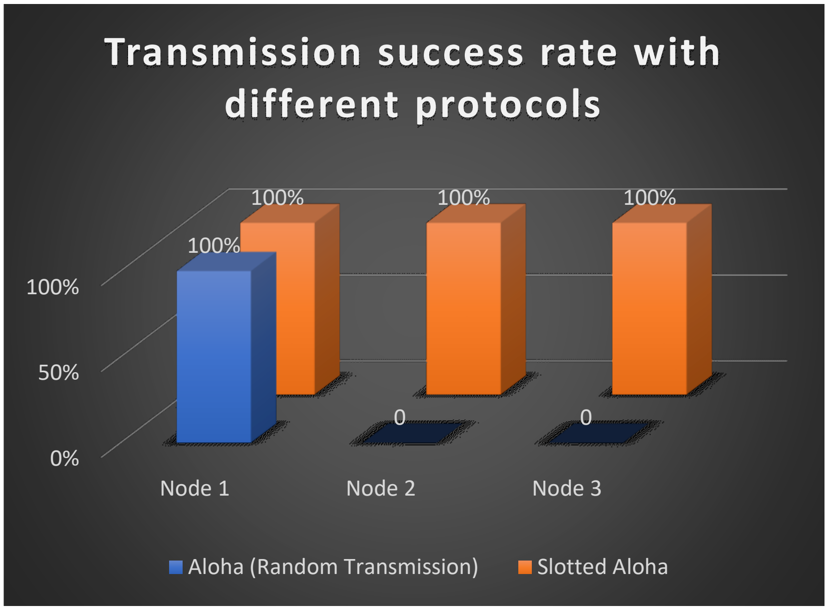


Figure 21. Transmission Using Different Protocols

[5] propose an approach called Slotted Transmission with Collision Avoidance (ST/CA). This method employs the slotted transmission where the uplink period is divided to the number of slots. The nodes sense the channel with Channel Activity Detection to find either the channel is idle or not. LoRa node’s ability to identify either a channel is busy or not can be seen as a good thing but then the collision avoidance mechanism must be designed carefully. So far for our scenario with 3 nodes this works well, but this can be another work in the future on how to avoid this collision when the transmission using multiple nodes in a big area.

Another thing to be taken into consideration is to manage an effective and efficient network transmission, considering how important and how valuable is the data that we transmit and how much its contribution to give information to the end user. Often the data we are transmitting already stale or not up to date, or the data that we transmit have captured by the other end nodes, so it is important to make sure data transmitter to the receiver as timely as possible.

3.3. Value of Information Analysis

Next step we want to evaluate the network that we have designed, considering the cost and energy for sending those updates, we want to keep in mind that we only want to send data that will give valuable information. In the model that we are currently deploying, we indicate end nodes which will send the update to the gateway/receiver by LoRa modulation.

As our main objective is to reduce cost and energy on the transmission so we try to find metrics that can reduce our transmission frequency. We know that on our network often our sensor nodes sending redundant data which actually have sent few times, if the cost of sending is really small it is not a big problem but when we spend a lot of cost for sending a redundant transmission it is then seen as impulsive operation.

As what we have mentioned in the previous step, we use discrete time slot for node to send update, for the sake of efficiency we want to let each node decides either it will send the packet or stay idle/deep sleep. So for the time slot, we want to do it in linear order, in which the previous sensor slot always the closest neighbor of sensor interest and we assume the transmission will always successful as we have assigned slot for each node. We are aware of the needs of transmitting the data as timely as possible, but at the same time we need to consider the cost spent for each transmission.

We adopted the method implemented by [8] for this transmission model, we consider a discrete time axis slot as mentioned in previous work we call epochs ($\tau_i^{(k)}$), in which for each epoch a node decides either to send the packet or stay idle. We denote p as the probability of transmitting and $\{\tau_i^{(1)}, \tau_i^{(2)}, ..., \tau_i^{(n)}\}$ are the epochs in which sensor *i* sends update. This decision obviously affected by few metrics such as cost, cruciality of the packet data and Age of Information.

Given we have *n* sensor points, we want focus on computing based on sensor $S_i \in S_n$. In this case all the sensors do not coordinate with each other, they are only aware about their time slot and know nothing about others. As we have multiple sensors, so it means each sensor will have different AoI as mentioned by [25] and for each sensor different AoI on different epoch. Gateway/receiver interested to get fresh data from the node *i* so we will compute the Age of Information of packet from sensor *i* as below:

$$\delta_i = t - \max(\tau_i(k) , \qquad \tau_i(k) < t \qquad (1)$$

In which the $\tau i\ (k)$ is the time since the last message from sensor *i* received by receiver monitor, and $k = \{1, 2, 3, …., N\}$ are the number of epochs in which sensor *i* sends update. From this equation we can define that AoI is equal to zero when the current time on monitor

t is equal to timestamp $\tau i\ (k)$, in real life it is unlikely to happen since there are certain necessary time spent for the propagation and transmission even for small amount.

As the value of this notation will be affected by the node decision either to send or not with probability p (value from 0 to 1), we can correlate the expected AoI at the receiver monitor to probability of transmitting as below [28]:

$$\mathbb{E}[\delta i] = \frac{1}{p} - 1 \qquad (2)$$

If we want the freshest information then it means we want the expected AoI to be optimized by the probability of sending equal to 1, but as mentioned in [8] it became unacceptable since it means the sender node will have to send as frequent as possible, in fact there is cost for each transmission that we must consider. So, we want to give a penalty for each transmission operated by the sensor node by including the cost that will be spent for one transmission. We will extend this notation by considering the cost that will be accounted to the update probability, which we call penalty function:

$$K_1(p) = \mathbb{E}[\delta i] + cp = \frac{1}{p} - 1 + cp \qquad (3)$$

As we want to transmission probability to be as small as possible so we will adopt [8] in which we want to minimize the p value with $p^* = \sqrt{\frac{1}{c}}$, but then we will take into consideration the other metric that will affect the probability of transmitting which is the cruciality of the data. We are aware that in real life agriculture scenario there are critical situations in the case that expect us to act as soon as possible i.e., emergency case when there are extreme situations such as fire in the field or extreme weather.

We want to quantify these situations by introducing λ as the metric to present how critical is an update which value can be 0 and 1, which 0 to imply the packet is normal situation and 1 if the packet imply crucial and abnormal situation that receiver need to know as soon as possible. So, we want to make 3 conditions in which node will decide whether to send the packet or not:

- p* $\geq 0{,}5\ and\ \lambda = 0\ send\ the\ packet$
- p* < 0,5 and $\lambda = 0$ stay idle/don't send packet
- for all p* when λ = 1 send packet

This decision then will impact the value AoI for sensor interest i, AoI will keep increasing when the node decided to not send. To overcome the case when node might not want to send all the epochs because of the node so we want to make condition a node must send data after 3 epochs of not sending which we will include this as abnormal situation that will assign value 1 to λ.

Further we want to see AoI value as main metric for the Value Information correlation, like [8]. Then we are interested in finding another factor to reduce transmission probability. The network designed to be using multiple sensors so it then become important to keep in mind that the previous sending sensor (S_{i-1}) might have capture data that is useful for the interest sensor $i \in N$, so we want to involve the usefulness of the other sensor captured data.

We will annotate this weight of useful information as α_{i-m} (m = {i-1, i-2, i-3, …., i-n} which its value depends on the previous sensor, the more useful its captured data the higher the value of α, which value start from 0 to 1. We can also do further calculation in which sensor *i-2* until i-n also possible to have correlated data for our network. We denote this situation as $\mathbb{1}$ which value will be 1 if there is useful information and 0 if previous sensor doesn't have any useful information for our sensor interest.

$$\text{VoI}_i = [\delta_i - (\sum_{m=1}^{n} \propto_{i-m} . \delta_i). \mathbb{1}(\delta_i \cap \delta_{i-m})] \tag{4}$$

$\mathbb{1}$ (.) is a characteristic function which value = 1 Boolean condition is true and the value become 0 if the Boolean condition is false. This value of AoI obviously depends on node decision either to send update or not, when the node decides to send update it means its AoI will increase by the time until the second and next epoch. In the last step we want to evaluate also the VoI, in which for example when we spend energy to transmit the data but then VoI we got is minus value, then it means we spend transmission cost for 0 information. So, we want to let our network discard the packet which has this below threshold VoI.

IV. RESULTS

We have done the simulation with MATLAB by assigning different costs to the node interest and lambda which imply how crucial is the data, and we have seen in the graph at certain costs the node decides to not send data which then will increase the AoI of the interest node in the receiver monitor and further will affect the Value of Information.

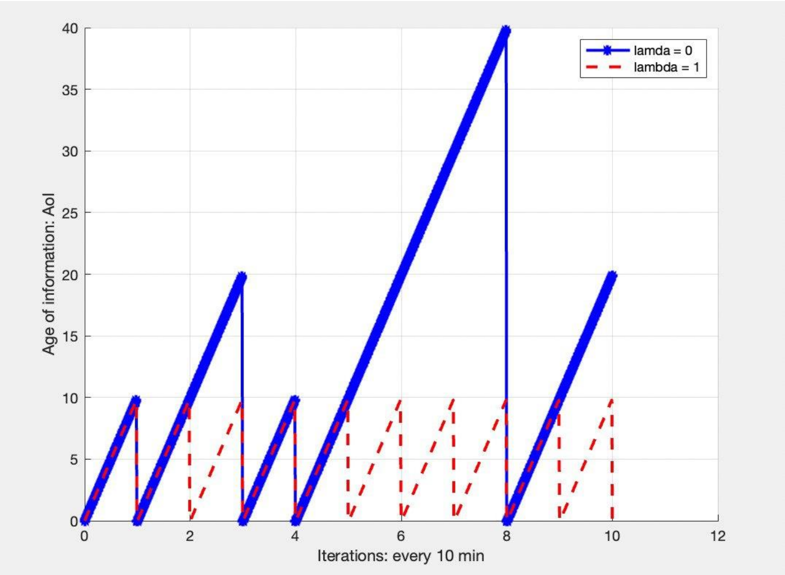


Figure 22. AoI Simulation with different cost

The figure has shown 2 scenarios in which λ equal to zero when it is normal situation and λ equal to one when it is abnormal situation. We can see in the figure that higher value of cost makes our network limits the update, when the probability of sending lower than 0.5 then node will decide to not send which increases the AoI. Let's say we have sensor *i* on its 2nd epoch based on the cost it decided to not send as in the figure with blue line, so then it will continue increasing its AoI until the 3rd epoch which then it decides to send, so this will decrease the AoI value back to zero.

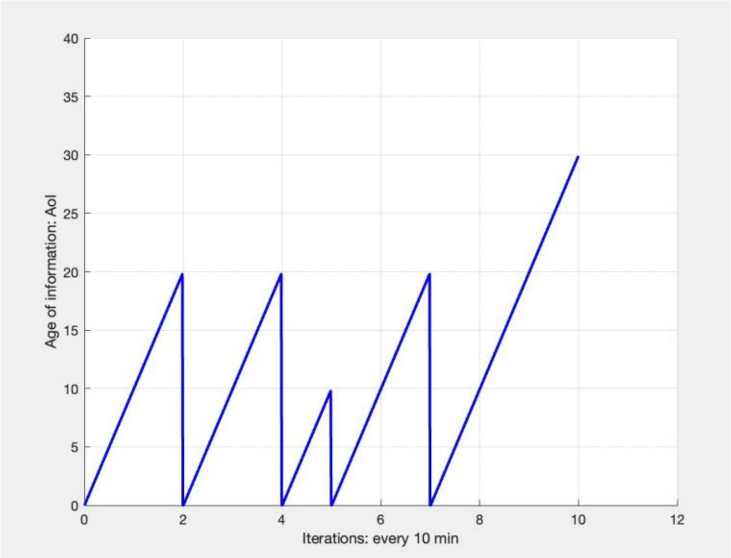


Figure 23. AoI Evolution with different λ (0 and 1) and cost

We also have simulated the previous scenario by applying random λ, so now the node decides based on 2 metrics, cost and λ. Even when the probability of sending lower than 0.5 but the λ has value 1 the node has no choice other than sending the data. Then we will assume this Value of AoI is the VoI for interest sensor node, but we want to keep in mind that there is probability that the other sensor node already captures correlated data, so we want to reduce this weight of correlation from the VoI of sensor interest with the formula (4).

We assigned random α which weight value is dependent on how much correlation it has to sensor *i,* in which we want to keep in mind a neighbor node only will be able to capture correlated data maximum 30% for interest sensor node data as they are always located in different points and they capture on different timing (slot).

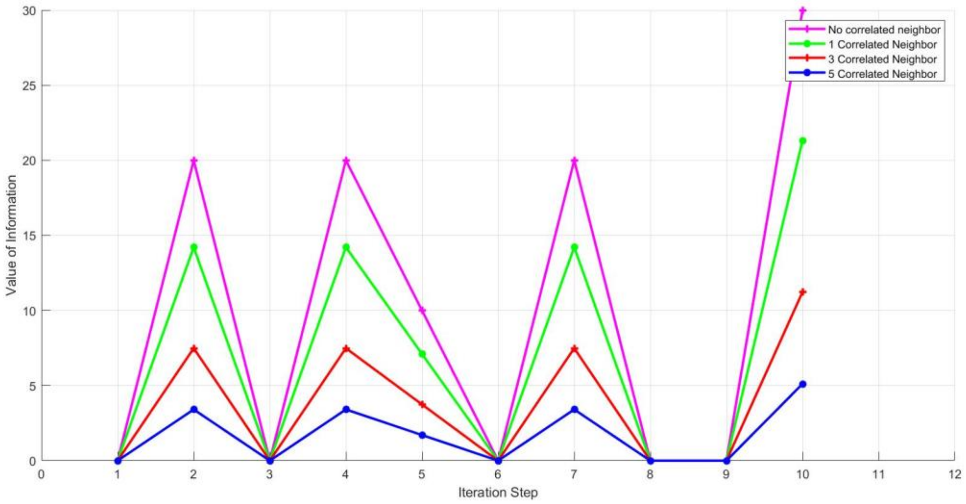


Figure 24. Value of Information on Different Number of Correlated Sensor

We have extended the AoI evolution from Figure 23 into the computation of VoI as shown in Figure 24, VoI at value 0 implies that the node did not send packet. We tried to compare how VoIs change based on correlated sensor neighbors, with different percentage of correlation, we have assigned randomly different weight for each different correlated sensor. As we have seen in the graph Figure 24 the existence of neighbor node which captured the correlated data reduced our sensor interest's VoI, doesn't always mean a greater number of correlated sensor nodes then the lower will be value of VoI.

This really depends on how much percentage of the correlated the sensor neighbor have captured. For example, on the red line there are three neighbor nodes captured correlated data with α = [0.0473 0.2912 0.2872] instead, the blue line which describes the case with 5 correlated neighbor nodes have smaller α values as follow: α = [0.1456 0.2401 0.0426 0.1256 0.2747]. There is possibility that even if there is only other 1 correlated node, but it has a high weight of α, it can deliver packet from node interest has lower Value of Information than when there are 3 correlated nodes with low value of α.

There actually an interesting hypothesis we can take from this case, which the neighbors might possibly have also captured the same data, for example let's say neighbor 1 capture 37% correlated data with sensor interest and neighbor 2 captured 25% correlated data to sensor interest. There is a probability that neighbor 1 and 2 captured certain amounts of same data of sensor interest, this will be our recommendation for the future work analyzing how correlated neighbors might capture the same data.

We also have simulated this scenario when the node always sends, from Figure 22, the same case before we try to limit the transmission.

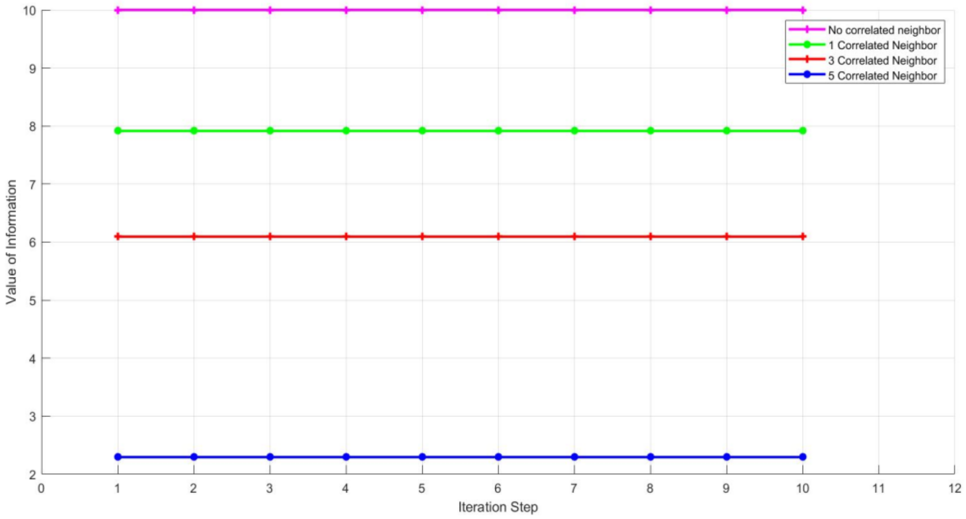


Figure 25. Voi Evolution of a Node Updates at Each Iteration

Figure 25 shows how the VoI decreased by the existence of correlated sensor nodes. From Figure 24 and Figure 25 we conclude that not sending the updates like on iteration 1,3,6,8, and 9 on Figure 24 sometimes better than sending updates which actually will not give any benefit for our network, simply saying we spend energy cost and traffic on the network for nothing.

On the cases like this we would like to propose a network design which is on simplest action, the network can discard the packet with VoI below the threshold. This at least will reduce the traffic and collision on the network, however further work should be done on how to deploy this model practically.

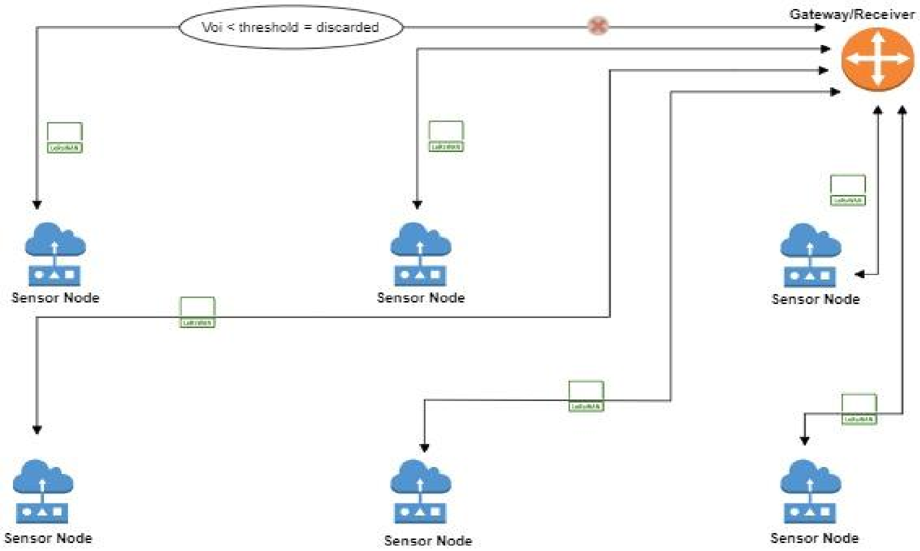


Figure 26. Network Model Proposed

There still a lot of things to observe deeper in term of analyzing the Value of Information on Wireless Sensor Network, designing the effective model based on how valuable the packet we transmit. This can be interesting research for the future how actually placement of the nodes on the practical situation performs by computing its Value of Information, what is the best network modelling to make sure that the nodes we deploy giving beneficial outcomes.

V. CONCLUSIONS AND FUTURE WORK

We have conducted a technical work in setting up multiple nodes for the LoRa transmission network, we tried to avoid collision by implementing slot time for each node. We also aim to reduce the traffic on the normal situation by letting nodes decide either to send the packet or not based on the penalty cost, this has helped us to reduce the transmission traffic until 50 % by the average showed by the Age of Information Evolution.

We also have done a set up in which a node must send the packet when the captured data is out of normal environmental situation, so the receiver can take further action immediately. To avoid cases when a node does not want to send at all iterations, we put a threshold which a node must send after a certain iteration which included as $\lambda = 1$ case. In the future work we are interested to know how this scenario and its VoI evolution will change if we apply Discounted Age of Information as our main metric as what [38] have proposed.

We have compared how the Value of Information captured by a sensor interest changed when there are neighbor sensor nodes capture correlated data. As on our result shows the greater number of neighbors capturing the correlated data the lower the VoI of sensor interest, this shows that in most real cases we send updates for no Value. It means on the cases like this, it will be interesting to analyze on practical situation how the placement of nodes can affect the Value of Information and how many sensor nodes do we need for certain agriculture area, given that often they capture the same data, so we do not really need to employ many nodes.

Or in the cases where we must deploy certain number of nodes in the agriculture field, considering an Energy Harvesting (EH) monitoring node [39] might be interesting to analyze, we want to know how much this node implementation will reduce the cost on our network.

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