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Intelligent and Reliable Ferry Route for IoT Networks Using Polling Systems Theory

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Abstract
The objective of this article is to propose a model, which makes it possible to design a reliable and intelligent path of the mobile ferry, to ensure communication between the connected objects and the gateway (destination). The IoT network is made up of quasi-static objects and a single mobile ferry, for communication. We consider the pure birth process, to model the reliability of IoT network objects. We consider the case of an IoT network with a single mobile ferry, and the case of an IoT network with N mobile ferries. We also studied the impact of the density of objects in the IoT network, and the rate of failed objects on the reliable and intelligent path of the mobile ferry.

Keywords: Internet of Things (IOT), Reliability Nodes, Mo-Bile Ferry, Stochastic Process, Polling Systems Theory

Introduction
The Internet of Things (IoT) is a global infrastructure for the information society, which provides advanced services by in- terconnecting objects (physical or virtual) through the Internet. Conceptually, the Internet of Things characterizes connected physical objects with their own digital identity and capable of communicating with each other. This network somehow creates a bridge between the physical world and the virtual world. From a technical point of view, the Internet of Things consists in the direct and standardized digital identification of a physical object thanks to a wireless communication system which can be an RFID, Bluetooth or Wi-Fi. Connected objects produce large amounts of data, the stor- age and processing of which are part of what is called big data. In logistics, it can be sensors that are used to track goods for inventory management and routing. In the area of the environment, we are talking about sensors monitoring air quality, temperature, noise level, condition of a building.

In home automation, the Internet of Things covers all commu- nicating household appliances, smart meters and connected security systems of home automation box type devices. The Internet of Things phenomenon is also very visible in the field of health and well-being with the development of connected watches, connected bracelets and other sensors monitoring vital constants. A mobile ferry is a mobile relay that collects messages from quasi-static objects to gateways in a geographic area. Objects can be static or moving at a very slow speed which can be considered static. In the article, the authors present the conscious mobility of the Internet of Things (IOT) [1]. They propose the cognition algorithm of the social relationships of the nodes based on the social network. They quantify the social relationship of all the nodes by introducing the interconnection factor and the distance factor. Next, build cohesive subgroups and a mobile node probability tree to predict the trace of the mobile nodes. Finally, they determine the awareness service nodes in the target regions, through the transfer of confidence and the calculation of probabilities. The authors of the article discuss the growing number of mobile devices with detection capabilities in communities, they argue that the reliability of community IoT systems can be improved by taking advantage of mobility [2]. They highlight key research challenges in building integrated community IoT ecosystems with mobile nodes and offer several possible approaches to improve detection cover- age and information quality. In work [3].

The Vehicle Internet (IOV) is an important part of IOT when the focus is on vehicles as the underlying smart devices. Vehicle communication in IoV is derived through Vehicular Ad-hoc Network (VANET). When simulating a VANET scenario, the movement of the nodes directly influences the overall performance. This move- ment is defined by multiple heterogeneous mobility models. Continuous research is carried out in order to bring these mobility models closer to mobility close to the real environ- ment. In, the authors improve an existing mobility analysis framework to perform mobility analyzes of mobile IoT nodes [4]. We also analyze different types of analytical applications in this context. This framework allows an IoT operator or an end user to make various decisions in a unified manner in the infrastructure operating mode. They also present the initial work for the ad-hoc mode of operation where one or more IoT gateway nodes are involved in carrying out a processing linked to the analysis. In article, the authors propose a new model for the IoT which offers mobility in terms of location change [5]. In addition, they offer their positional view of the components of the Mobile IoT model. In addition, they provide scenario applications for mobile IoT uses. The authors of the article offer the narrowband Internet of Things [6]. This technology supports mobility only with the cell in an inactive state. In this regard, it is important for mobile operators to optimize cell performance for a reliable narrowband Internet of Things service. They provide the operational characteristics of narrowband Internet of Things cells and a methodology for optimizing cell parameters with test results in the test bench as well as in a real operational field environment. In [7]. The authors treat the mobile Internet of Things as one of the new areas of IoT, due to mobility, requires a more demanding and rigorous solution in many ways, especially in terms of energy efficiency.

They offer a solution consisting of a fast and energy efficient hardware platform for the construction of fog layer installations of the mobile Internet of Things. In the work, the authors propose Mobility management, which is a desired functionality for the emergence of the Internet of Things (IoT) [8]. Mobility solutions increase connectivity and improve adaptability to changes in location and infrastructure. This work analyzes the relevance of Mobile IPv6 (Internet Protocol version 6) for constrained devices, thus it makes it possible to develop a light version of Mobile IPv6. The proposed Mobile IPv6 solution is aware of the requirements of IoT and presents the best solution for dynamic ecosystems in terms of efficiency and security adapted to the capabilities of IoT devices. The authors of the article aim to learn the mobility model of IoT devices to improve the efficiency of discovery [9]. Various techniques available for discovery of neighbors are discussed and it is shown that integrating knowledge into the process of node discovery leads to efficient resource planning. In the article, the authors discuss Routing on low-power networks which is a major challenge in IoT, due to its resource-constrained devices [10]. Some IoT applications where mobility and device-to-device communication are required, the routing protocol should have these properties with less power consumption. Many researchers have developed routing protocols for IoT that produce optimal device-to-device paths with reduced power consumption, but only a few of them support mobility. The rest of this paper is structured as follows. The section II details the mobility in IoT networks. In section III, we present the system model. We detail the ferry moving on circular path in the section IV. The last section summarizes this work and presents some future directions to enhance the paper.

Mobility in IOT Networks

A particular characteristic of IoT networks is the variation in their topology. Beyond the link quality which can be the source of variation (the transmission quality is such that the link is considered to be non-existent) the mobility of the elements generates changes in connectivity. A node of an IoT network moves, it can join or leave an IoT network at any time, that is to say being out of range of emission of a node of the network. The routing protocol, via a route maintenance procedure, is in charge of managing these topology changes. By design, it naturally adapts to them. A more sophisticated routing adaptation consists in taking into account the level of mobility of an element so as to choose stable routes, the stability of the route being able to bring about a performance gain. Indeed, if a route breaks, the routing protocol is able (if this is possible) to find another, but there will have been data losses generating a performance decrease, and therefore, avoiding using routes that are perhaps fast but short, the routing protocol can hope to increase its rate of information delivery. The problem for the implementation of this adaptation is to assess the stability of a link, for example with the mobility of an element.

Communication protocols in IoT networks are naturally designed to manage topology changes: appearance, disappearance of a link. The optimization sought by adaptation is more interested in the dynamics of evolution: rapid appearance of links, large number of appearances. Introducing adaptation techniques then consists in the protocol using environment parameters to choose its routes, to choose its architectural elements, or else to modify its operating mode, with or without architecture, reactive versus proactive, depending on the environment, the dynamics of topology evolution.

System Model

We consider a geographic area Δ in which a quasi-static IoT network is deployed. To send messages from objects to the gateway or to receive messages from the gateway to objects, a mobile ferry moves cyclically to serve the connected objects. We consider that the gateway is placed in the center of the Δ deployment zone.

Ferry's Route

The ferry travels on a closed cyclic path C at a constant speed c_1. Each point q on the ferry route is represented by a set of points $I(q) \subset \Delta$ closest to point q. The set $I(q)$ is made up of all the points $x \in \Delta$ with the projection of x on the trajectory C is q. The ferry continues to move after serving the connected object. Each time the mobile ferry stops to communicate with the connected object, it spends a time for acceleration c_2. We assume that the ferry route is cut by a line and the gateway is located at position 0.

Arrival Process

We assume the "uplink" traffic generated by the connected objects, and the "downlink" traffic which arrives at the con- nected objects. The uplink / downlink traffic arrives according to a punctual process marked independent $\{T_n, M_n\}$, where T_n is the instant of arrival of the point n^{th} and $M_n = \{x_n, \eta_n\}$ are the corresponding marks:

- T_n: is a Poisson process with the parameter λ.
- x_n: is the position of the object which follows the distribution P_x.
- η_n: is the size of the message. We define the first moment $\eta_b(x)$ and second moment $\eta_b^2(x)$.

We consider that the distribution of η is independent of the position of the connected object and the type of service (uplink or downlink), then $E[(\eta)] = \eta_b$ and $E[(\eta^2|x)] = \eta_x^2$.

Service Time

The mobile ferry can receive and send messages from or to connected objects at a distance d associated with a decreasing function $k(d)$. Each time the ferry stops, it spends additional time c_2 for acceleration. The total time required to broadcast an uplink / downlink message of size η, when the object is located at $x \in \Delta$ and the ferry at $q(x) \in C$ can be calculated

by $B(x, \eta)$, which is equal to the size η divided by the service rate.

$$B(x,\eta) = \frac{\eta}{K(\|q(x)-x\|)} + c_2$$

Where $q(x) := argmin_{q\in C}\|q - x\|$

Reliability Objects

We introduce the concept of reliability in the model. We consider a uniformly continuous distribution of objects P_x and we suppose that at any time there can be at most one object waiting at a point x. Let P_q be the mobile ferry distribution stops on C. We have P_q follows P_x with the equation:

$$P_q(A) := P_x(\cup_{q\in A} I(q))$$

We use a pure birth process to model the birth of faulty objects in the IoT network. Let k be the random variable corresponding to the number of defective objects from time 0 to t and ρ the rate of occurrence of faulty objects at the time t.

The probability of having exactly k defective objects at time t is given by the Poisson distribution with the mean ρt:

$$P_k(t) = \frac{(\rho t)^k}{k!} e^{-\rho t} \quad \forall k \in \mathbb{N}, \forall t \in \mathbb{R}$$

The expected number of objects failures at t is given by:

$$\begin{aligned} M(t) = E[k(t)] &= \Sigma_{k=0}^{n} k.\frac{(\rho t)^k}{k!} e^{-\rho t} \\ &= e^{-\rho t}\Sigma_{k=0}^{n} k.\frac{(\rho t)^k}{k!} \\ &= e^{-\rho t}(\rho t)\Sigma_{k=0}^{n} k.\frac{(\rho t)^{k-1}}{(k-1)!} \\ &= \rho t \end{aligned}$$

Let t' the time separating failure of two objects. The distribution function of the waiting time to the next failure is:

$$\begin{aligned} F_{t'}(t) &= P[t' < t] \\ &= 1 - P[t' \geq t] \\ &= 1 - P[k(t) = 0] \\ &= 1 - e^{-\rho t} \end{aligned}$$

The probability density of the interval time between failures is the derivative of the distribution function of the waiting time for the next failure:

$$f_{t'}(t) = \rho e^{-\rho t}$$

The mean time between failures is then the mathematical expectation of t':

$$E[t'] = \int_{t=0}^{\infty} t f_{t'}(t) = \frac{1}{\rho}$$

The ferry stops at any location q on the path C to distribute messages to active objects in the downlink service and/or to collect messages from the objects in the uplink service within its communication range and which belong to the segment $I(q)$. The only factor that could prevent a ferry from stopping is the proportion of the faulty objects.

Pareto Optimality

All objects are served when the ferry moves on C. Any object at a point $x \in \Delta$ has to wait for time $W(q(x))$ and the expected values of these waiting times $E[w](q)$ depend upon the point $q \in C$ standing where the ferry serves the object. **Solution:** We are interested in designing an intelligent optimal path which minimizes the integral of weighted expected waiting times at all the points in the cycle path C taking into account objects reliability in this design:

$$\int_0^{|C|} E[w](q)\delta(q)(1 - \frac{\rho t}{n})dq$$

- n: present the total number of objects in the IoT network.
- ρt: present the expected number of objects failures by time t.
- $1 - \frac{1}{\rho t}$: present the expected number of operational objects by time t as a percentage.
- $\{\delta(q)\}$: Appropriate positive weights that give a Pareto optimal solution for the problem of minimizing the ex- pected waiting times for all objects.

Ferry Moving on A Circular Path

In this section, we study a ferry moving in annular ring using the theory of continuous polling systems [9,10]. We discuss a design of an intelligent optimal path taking into account objects reliability that minimizes the virtual workload.

The ferry moves in cyclic closed path C inside an annular ring:

$$\Delta := \{x \in \mathbb{R}^2 : h_1^2 \leq |x| \leq h_2^2\}$$

Each point q in the cyclic path is associated to a line segment $I(q) \subset \Delta$, which is obtained using the nearest point. The ferry that represents the server of the polling system stops at the point $q \in C$ when there is an active object with downlink/uplink requests on $I(q)$. In this article, the line segments will be angular segments.

The ferry collects the downlink information from the destination (gateway) and distributes it to the corresponding objects. It also collects the uplink information from the active objects when it is traveling via the circular path. The Ferry is modelled by a mixed-service continuous polling system. We assume that the uplink and downlink arrivals occur with equal probabilities $p_{downlink} = p_{uplink} = \frac{1}{2}$. For calculating the moments of a polling system $b(q; 1)$ that represent the average service time of the objects we assume that the radius R of the arrival has a given density:

$$f_R(r) = \frac{2r}{h_2^2 - h_1^2}$$

The expected service time for the object corresponding to the point $q \in C$ represents the mathematical expectation of the service time. It is the first service moment that is given by the following equation:

$$b_{(q)} = E[B(x, \eta)] = E[\frac{\eta}{K(\|q - x\|)}] + c_2$$

The second moment represents the variance of the service time:

$$\begin{aligned}
b_{(q)}^2 &= E[(B(x,\eta))^2] \\
&= E[(\frac{\eta}{K(\| q - x \|)} + c_2)^2] \\
&= E[\frac{\eta^2}{(K(\| q - x \|))^2} + 2\frac{\eta}{K(\| q - x \|)} c_2 + c_2^2] \\
&= E[\frac{\eta^2}{(K(\| q - x \|))^2}] + 2E[\frac{\eta}{K(\| q - x \|)} c_2] + c_2^2 \\
&= E[\frac{\eta^2}{(K(\| q - x \|))^2}] + 2E[\frac{\eta}{K(\| q - x \|)} c_2] + c_2^2 + c_2^2 - c_2^2 \\
&= E[\frac{\eta^2}{(K(\| q - x \|))^2}] + 2E[\frac{\eta}{K(\| q - x \|)} c_2] + 2c_2^2 - c_2^2 \\
&= E[\frac{\eta^2}{(K(\| q - x \|))^2}] + 2c_2(E[\frac{\eta}{K(\| q - x \|)} + c_2) - c_2^2 \\
&= E[\frac{\eta^2}{(K(\| q - x \|))^2}] + 2c_2 b_{(q)} - c_2^2
\end{aligned}$$

The rate function resulting from losses in the wireless medium considers some attenuation in the direct path. Let $\beta = 2\alpha$ the path loss factor, the rate service function is:

$$k(d) = (1+d^2)^{-\alpha} = \frac{1}{(1+d^2)^{\alpha}}$$

Definition 1: We called virtual workload [13] the total service time required by all the waiting users. According to the polling system theory, the virtual workload for mixed service is given by the following equation [9]:

$$V_{mix}(l) = \frac{\lambda^2 b_l^{(2)} b_l}{2(1-\lambda b_l)} + \frac{3\lambda b_l |C_l|}{4c_1(1-\lambda b_l)} \quad (E)$$

The optimal path taking into account objects reliability is the route which minimizes the virtual workload $V_{mix}(l)$ according to the equation (E). It can be easily seen that $V_{mix}(l)$ depends upon l only via $|c_l|$ and the moments b_l, b_l^2. By studying the expression for the virtual workload, we remark that if the speed of the ferry is high or the annular ring is large, the optimal radius will be determined only by the moments of the service time. The second term in (E) tends to zero then $V_{mix}(l)$ depends upon l only via the moments b_l, b_l^2.

Ferry Moving in One Path

In this subsection, we consider optimal path C_l placed inside the annular area Δ, the ferry moves on one concentric circle of radius l in the annular ring (see figure 1) according to the following equation:

$$C_l = \{q \in \mathbb{R}^2 : \| q \| = 1\}$$

Let L_x the angle mark the object in P_x and L_q the angle mark the ferry in C relative to the line that map the ferry route in the direct sense. In this case, the line segments will be an angular segment (see figure 1) according to the given equation:

$$I_{(q)} = \{x \in \Delta : L_x = L_q\} \quad \forall q \in C_l$$

The moments of the service, $\forall q \in c_l$, are:

$$\begin{aligned} b_{(l)} &= \eta_b \int_{h_1}^{h_2} (1+(r-l)^2)^{\alpha} \frac{2r}{h_2^2 - h_1^2}(1-\frac{\rho t}{n})dr + c_2 \\ b_{(l)}^2 &= \eta_b^2 \int_{h_2}^{h_1} (1+(r-l)^2)^{2\alpha} \frac{2r}{h_2^2 - h_1^2}(1-\frac{\rho t}{n})dr + 2c_2 b_{(l)} - c_2^2 \end{aligned}$$

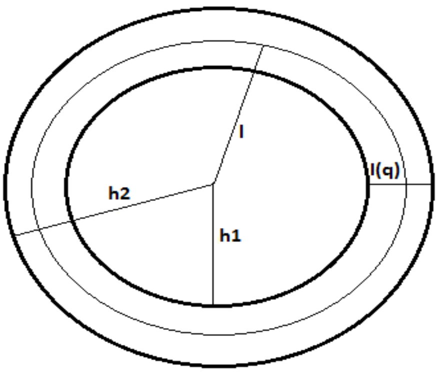

Figure 1: One Ferry in an Annular Ring

For $\alpha = 1$ we get:

$$b_l = \eta_b(1-\frac{\rho t}{n})\left(\frac{1}{2}(h_1^2+h_2^2+2) + l^2 - \frac{4l(h_1^2+h_2^2+h_1h_2)}{3(h_1+h_2}\right) + c_2$$

$$\begin{aligned} b_l^2 &= \frac{\eta_b^2}{15(h_2^2-h_1^2)}(1-\frac{\rho t}{n})(-5h_1^6 + 24h_1^5 l - 15h_1^4(3l^2+1) \\ &+ 40h_1^3(l^3+l) - 15h_1^2(l^2+l)^2 h_2^2(5h_2^4 - 24h_2^3 l + 15h_2^2(3l^2+1) \\ &- 40h_2(l^3+l) + 15(l^2+1)^2)) + 2c_2 b_l - c_2^2 \end{aligned}$$

The optimizer of the expected service time can be calculated as:

$$l_b^* := argmin(b_{(l)})$$

Any calculation made, we get:

$$l_b^* = (1-\frac{\rho t}{n})(\frac{2(h_1^2+h_2^2+h_1h_2)}{3(h_1+h_2)})$$

By studying the expression of the virtual workload, the optimal radius l^* of the mobile ferry will be determined only by the moments of the service time when the annular ring is large or the speed of the ferry is high. Then the path which minimizes the moments of the service time b_l^1, b_l^2 is exactly the path that minimizes the virtual workload. In these scenarios, we have:

$$l^* \approx l_b^* = (1-\frac{\rho t}{n})(\frac{2(h_1^2+h_2^2+h_1h_2)}{3(h_1+h_2)})$$

N Ferries Moving Simultaneously in N Paths

The ferry moving in one circular path may not be optimal when the area is larger. In this subsection, we consider N ferries $F := [F_1, F_2, F_3..., F_N]$ moving simultaneously and independent of each other with the same speeds on circular paths $1 := [1_1, 1_2, 1_3..., 1_N]$. Each ferry communicate with the destination (gateway) when it touch the angle $L_x = 0$.

Let $B(x, p) = \{y : ||y - x|| < p\}$ the open ball with center x and radius p and $B(x, p)$ its closure, each n^{th} ferry covers the area:

$$A = \overline{B}(0, p_n) - \overline{B}(0, p_{n-1})$$

Each n^{th} ferry moves on one concentric circle of radius 1_n in the annular ring A (see figure 2) according to the equation:

$$C_n = \{q \in \mathbb{R}^2 :\| q \|= 1_n\}$$

In This case, the line segments will be angular (see figure 2) according to the given equation:

$$I_n(q) = \{x \in (\overline{B}(0, p_n) - \overline{B}(0, p_{n-1})) : L_x = L_q\}$$

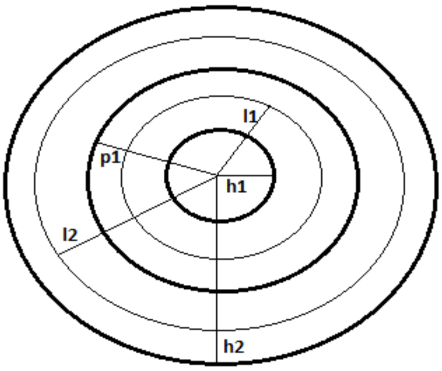

Figure 2: Two Ferries in an Annular Ring

We model each mobile ferry by a separate continuous polling system. The moments of the service times for the n^{th} ferry are:

$$\begin{aligned} b_{(n,p,l)} &= \eta_b \int_{p_{n-1}}^{p_n} (1+(r-l)^2)^\alpha \frac{2r}{p_n^2 - p_{n-1}^2}(1-\frac{\rho t}{n})dr + c_2 \\ b^2_{(n,p,l)} &= \eta_b^2 \int_{p_{n-1}}^{p_n} (1+(r-l)^2)^{2\alpha} \frac{2r}{p_n^2 - p_{n-1}^2}(1-\frac{\rho t}{n})dr \\ &+ 2c_2 b_{(n,p,l)} - c_2^2 \end{aligned}$$

For each n^{th} ferry, the optimizer of the expected service time is:

$$l_{n,b}^* = argmin(b_{(n,p,l)})$$

Any calculation made, we get:

$$l_{n,b}^* = (1-\frac{\rho t}{n})\left(\frac{2(p_{n-1}^2+p_n^2+p_{n-1}p_n)}{3(p_{n-1}+p_n)}\right)$$

For illustration, we consider an example with 2 ferries moving in the annular area and supporting mixed service, the moments of the service time, for $\alpha = 1$, are :

For the first ferry

$$\begin{aligned}
b_{(n_1,p_1,l_1)} &= \eta_b \int_{h_1}^{p_1} (1+(r-l)^2)^{\alpha} \frac{2r}{p_1^2-h_1^2}(1-\frac{\rho t}{n})dr + c_2 \\
&= \eta_b(1-\frac{\rho t}{n})\left(\frac{1}{2}(h_1^2+p_1^2+2)+l^2-\frac{4l(h_1^2+p_1^2+h_1p_1)}{3(h_1+p_1)}\right) \\
&+ c_2 \\
b^2_{(n_1,p_1,l_1)} &= \eta_b^2 \int_{p_1}^{h_1} (1+(r-l)^2)^{2\alpha} \frac{2r}{p_1^2-h_1^2}(1-\frac{\rho t}{n})dr \\
&+ 2c_2 b_{(n_1,p_1,l_1)} - c_2^2 \\
&= \frac{\eta_b^2}{15(p_1^2-h_1^2)}(1-\frac{\rho t}{n})(-5h_1^6+24h_1^5 l-15h_1^4(3l^2+1) \\
&+ 40h_1^3(l^3+l)-15h_1^2(l^2+l)^2 p_1^2(5p_1^4-24p_1^3 l \\
&+ 15p_1^2(3l^2+1)-40p_1(l^3+l)+15(l^2+1)^2)) \\
&+ 2c_2 b_{(n_1,p_1,l_1)} - c_2^2
\end{aligned}$$

For the second ferry

$$\begin{aligned}
b_{(n_2,p_1,l_2)} &= \eta_b \int_{p_1}^{h_2} (1+(r-l)^2)^{\alpha} \frac{2r}{h_2^2-p_1^2}(1-\frac{\rho t}{n})dr + c_2 \\
&= \eta_b(1-\frac{\rho t}{n})\left(\frac{1}{2}(p_1^2+h_2^2+2)+l^2-\frac{4l(p_1^2+h_2^2+p_1h_2)}{3(p_1+h_2}\right) \\
&+ c_2 \\
b^2_{(n_2,p_1,l_2)} &= \eta_b^2 \int_{h_2}^{p_1} (1+(r-l)^2)^{2\alpha} \frac{2r}{h_2^2-p_1^2}(1-\frac{\rho t}{n})dr \\
&+ 2c_2 b_{(n_2,p_1,l_2)} - c_2^2 \\
&= \frac{\eta_b^2}{15(h_2^2-p_1^2)}(1-\frac{\rho t}{n})(-5p_1^6+24p_1^5 l-15p_1^4(3l^2+1) \\
&+ 40p_1^3(l^3+l)-15p_1^2(l^2+l)^2 h_2^2(5h_2^4-24h_2^3 l \\
&+ 15h_2^2(3l^2+1)-40h_2(l^3+l)+15(l^2+1)^2)) \\
&+ 2c_2 b_{(n_2,p_1,l_2)} - c_2^2
\end{aligned}$$

The optimizers of the expected service time are:

$$\begin{cases} l_b^{*,1} = argmin(b_{n_1,p_1,l_1}) \\ l_b^{*,2} = argmin(b_{n_2,p_1,l_2}) \end{cases}$$

Any calculation made, we have:

$$\begin{cases} l_b^{*,1} = (1-\dfrac{\rho t}{n})(\dfrac{2(h_1^2+p_1^2+h_1p_1)}{3(h_1+p_1)}) \\ l_b^{*,2} = (1-\dfrac{\rho t}{n})(\dfrac{2(p_1^2+h_2^2+p_1h_2)}{3(p_1+h_2)}) \end{cases}$$

Numerical Analysis

In this section, we present the numerical analysis part in two numerical examples. The first illustrates the results in the case of a single ferry, which moves moves in an annular zone. The second shows the case where we have several ferries traveling simultaneously in the same area.

The First Scenario

We consider an IoT network with a single destination (gateway), the network is distributed in an annular zone with an area s = 15693.72m^2. A mobile ferry travels through the area to provide mixed service to network objects. The optimal radius l^* will only be determined by the moments of the service time.

Figure 3 Represents the optimum radius as a function of the faulty objects, for different densities for each density, note that the optimal radius starts from the value 33.34m, and when the number of faulty objects increases in the area, the optimal radius converges to the zero radius. Figure 4 represents the optimal radius as a function of time, for different values of the rate of the faulty objects. We notice that the optimal radius starts from the value 33.34m, and as time increases the optimal radius converges to zero radius, and as the rate of failed objects increases in the array, the optimal radius quickly converges to the zero radius.

The Second Scenario

In this scenario, we consider an IoT network with a single destination, distributed in an annular zone with an area s = 40185.72m^2. Two mobile ferries move simultaneously and independently of each other with the same speed to provide.

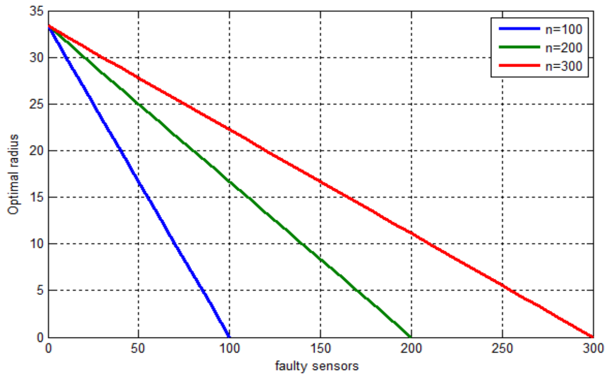

Figure 3: Optimal Radius Vs. Faulty Objects for One Ferry in an Annular Ring

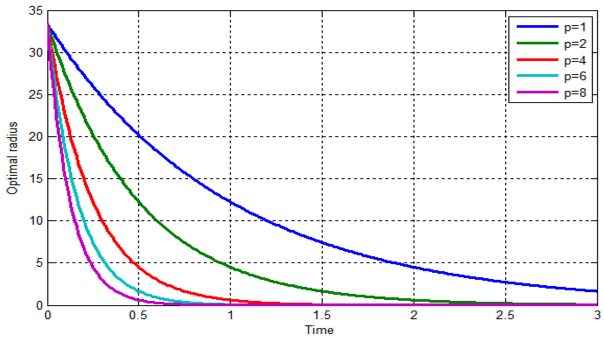

Figure 4: Optimal Radius Vs. Time for One Ferry in an Annular Ring

mixed service to objects. The optimal radius $1*$ for each ferry will be determined solely by their moments of service time. Figure 5 shows the optimum radii as a function of the number of faulty objects in the area, in the case of several ferries. Note that the first optimal radius varies between the value 27.01m and 0m, and the second optimal radius varies between the value 62.4m. For optimal radii, as the number of faulty objects increases in the area, the two optimal radii converge to the zero radius.

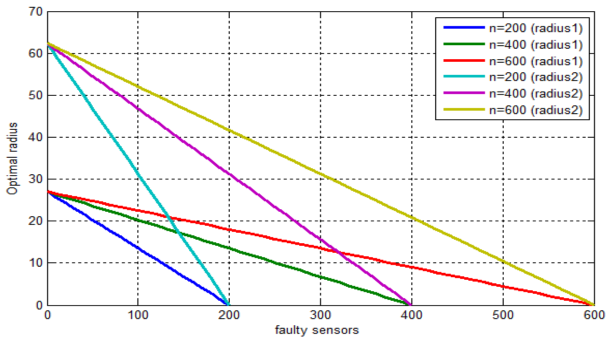

Figure 5: Optimal Radius Vs. Faulty Sensors for Two Ferries in an Annular Ring

Figure 6 shows the optimal radius as a function of time, for an IoT network with several mobile ferries, and for several different failed object rates. Note that each optimal radius varies within a well-defined interval. The first radius starts from the value 27.01m, and the second radius starts from the value 62.4m. As the time increases, the two optimal radius converge to the zero ray. And as the rate of failed objects increases in the array, the two optimal rays quickly converge to the zero radius.

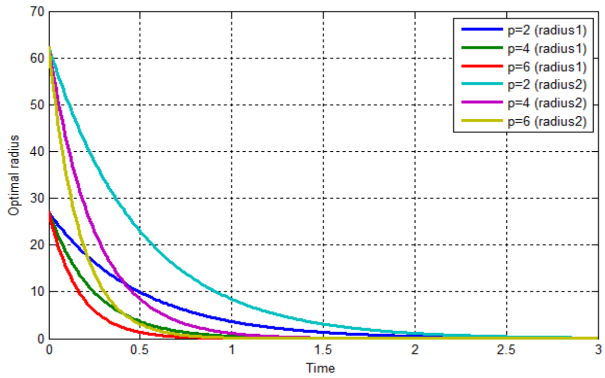

Figure 6: Optimal Radius Vs. Time for Two Ferries in an Annular Ring

Conclusion and Perspectives

In this article, we have proposed a new smart and reliable model of the mobile ferry. This model makes it possible to calculate the optimal radius of the mobile ferry, taking into account the reliability of the objects. Our work focuses on a mixed service, using continuous polling systems. We have shown that the path of the mobile ferry depends on the reliability of the objects. The optimal radius of the mobile ferry varies within a well-defined interval, it depends on: the density of the network, the number of faulty sensors, the number of ferries in the area, the surface of the area, and other parameters.

For future work, we propose to generalize our model to the case of an IoT network with several destinations (gateways).

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