Flying Ubiquitous Sensor Networks as a Queueing System

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***Abstract*— The Flying Ubiquitous Sensor Networks (FUSN) includes two segments: ground and flying. The ground segment is the traditional ubiquitous sensor network (USN) with field or mobile sensor nodes. The flying segment represents the one or more small Unmanned Aerial vehicles (sUAV) which are equipped with sensor nodes as well. The sUAV can collect data from ground sensor fields. Furthermore, the sUAV can be a temporary cluster head for ground sensor nodes during this collecting.**

The sUAV is considered as the queuing system in the paper. Two general models are analyzed. There are the ground segments of sensor nodes with known coordinates on the first model. The sensor nodes with unknown coordinates are on the second model. The schedule collection procedure is proposed for the first model. The distribution function for requests number from sensor nodes is defined for the second model.

***Keywords*— Flying Ubiquitous Sensor Network, small Unmanned Aerial Vehicle, queuing system, distribution function**

I. Introduction

The Internet of Things (IoT) is the new ITU-T concept for the network development. The ITU-T define IoT as a future global infrastructure: "In a broad perspective, the IoT can be perceived as a vision with technological and societal implications. From the perspective of technical standardization, IoT can be viewed as a global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on, existing and evolving, interoperable information and communication technologies" [1, 2]. Things are considered as things from the nature and information worlds.

The IoT is based on the Ubiquitous Sensor Network (USN). The USN is used for monitoring 2D and 3D spaces, phenomena, processes and so on. The sensor nodes form a network which can be distributed on the spaces as whole network or as a separate fragment. This separate fragment is usually named as a sensor field. The sensor field can be located in the arduous zone or in the rural area. The sensor network architecture is hierarchical with cluster structure generally. The cluster head selection is one of the most important investigation topics up to now [3, 4]. The USN cluster structure increases network life-time and coverage, reduced energy consumption. The data collection is provided by sink or base station. The data collection for distributed sensor fields is difficult while using these methods. The new collection of data methods search is needed for distributed sensor fields.

The Flying Ad Hoc Networks (FANET) is used for monitoring and controlling the arduous zone and the rural area in the last time [5, 6]. The applications can include video dissemination via FANET [7], military cases [8]. The comparison of different protocols [9], methods for reducing energy consumption [10], and data synchronization method [11] are the more investigation areas for FANET.

The Flying Sensor Networks was used in the [12] to search, detect and locate ground targets. The ground targets were the mobile radio frequency emitters.

We propose a new network FUSN which consists of the separate ground sensor fields and one or more sUAV that are equipped with sensor node or sensor nodes. The main mission of FUSN is the collection data from the sensor fields which can be located in the arduous zone or in the rural area. The FUSN structure with one sUAV and m sensor fields is shown on the fig.1.

II. FUSN Model with Known Sensor Nodes Coordinate

The motion path of the sUAV algorithm that is discussed above suggests that his movement during data exchange with the network node $s = \tau_0 \cdot v$,where τ_0 - duration of interaction with one node, and v - sUAV speed is negligibly small compared with the radius of the coverage area, i.e. $\frac{\tau_0 \cdot v}{R} \to 0$.

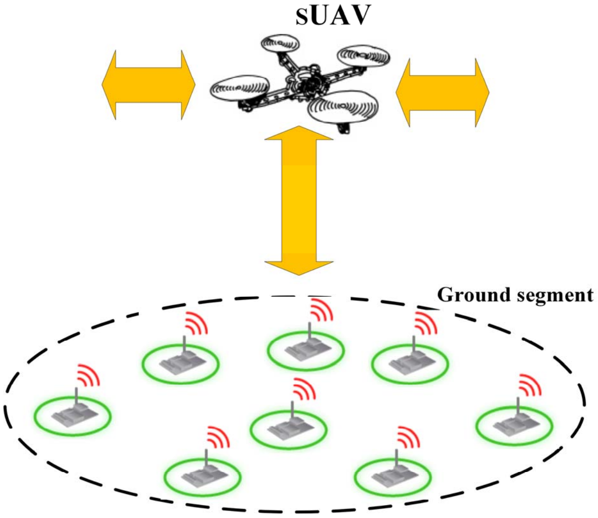

Figure 1. The FUSN structure

When R is a final condition is met for all network nodes within the service area only if $v \to 0$ or $\tau_0 \to 0$, i.e. at the point of immobility sUAV skimming or instant reading data (fig.2). If $v > 0$ and $\tau_0 > 0$, assume such a state that the service area at the boundary opposite to the direction of motion are the network nodes, they cannot be served because their time spent in the area t_C will be equal null.

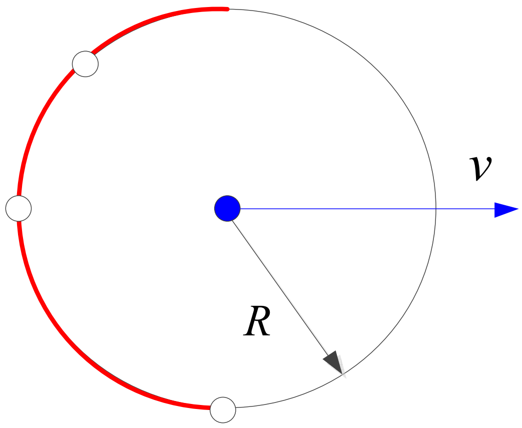

Figure 2. Unserviced nodes on the border of the service area of the sUAV at v>0

Based on the residence time of the node in the service area, it is possible to determine the boundary of the region while the node will be served at a given speed of movement of the sUAV.

The minimum time equal to the time of service τ_0, consequently, the distance to the boundary is equal to $S_C = v \cdot \tau_0$.

The area from which the assembly can be serviced during τ_0, shown in Figure 3.

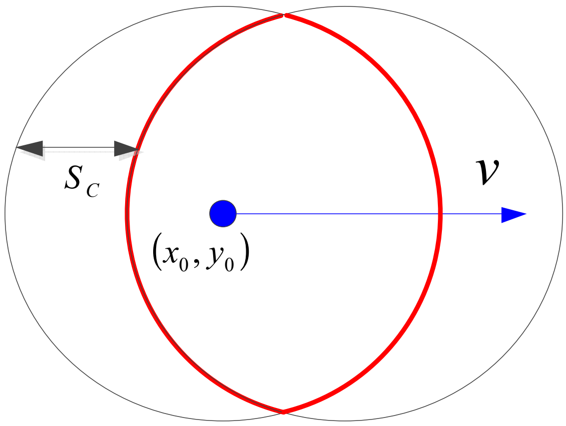

Figure 3. sUAV service areas with v>0

Thus, if at some point in time t sUAV must conduct a communication session, moving with the velocity v, it is important to choose the node from the specified area. The node which lies to the left of this area cannot be served. These arguments are valid when considering a single node. If there is a set of nodes in the range of the sUAV, they need for their services more than τ_0 time that requires thorough consideration.

When servicing a plurality of nodes, the sUAV can be considered as a queuing system, the input of which receives requests (nodes in the service area) that can be expected in service during their stay in the area of accessibility. The applications (nodes) that have not been serviced during this time are rejected. Flow rate is dependent on the radius of the service area, the density of nodes and speed of the sUAV. Some time is spent on the service of node sUAV during the period of service node must be in the area of accessibility.

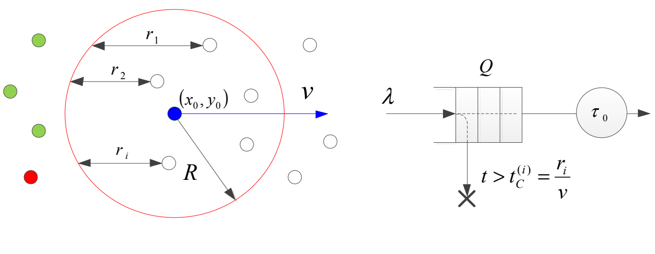

Figure 4. sUAV as a queueing system

Maintenance task is useful to consider a set of nodes for the two types of cases.

In the first case, the coordinates of nodes are known. In this case, the input of the system enters a deterministic flow of applications. Optimization of the operation of this system is reduced to the choice of law (schedule) service nodes.

In the second case, it is assumed that the coordinates of the nodes are not known. The input to the system enters a random stream of applications. To select the operation mode of this system the determination of the probability of failure dependence in the service of its parameters is required.

Known coordinates of the (deterministic flow applications)

Suppose that at some time in the service area of said region there are multiple nodes, while moving at a speed v the maximum number of nodes that potentially may serve travel time is determined by the distance of the sUAV - R

$$k_{MAX} = \left\lfloor \frac{R}{v \cdot \tau_0} \right\rfloor \qquad (1)$$

However, this is only a potential number. For example, if we assume that all the nodes are indicated on the left border region, it will be possible to serve only one of them, fig.5a. But if they are on a straight line passing through the center of the service area and coinciding with the direction of motion of the sUAV, and if they are arranged at intervals $\tilde{s} = v \cdot \tau_0$, they can all be catered, fig.5b.

This is certainly only possible if the service will be started from the latter, i.e. closest to the left edge of the coverage area of the site. If you start the service from the first (rightmost) of the node, the number of serviced sites will be less because most of them will leave the coverage area during the first and subsequent service node.

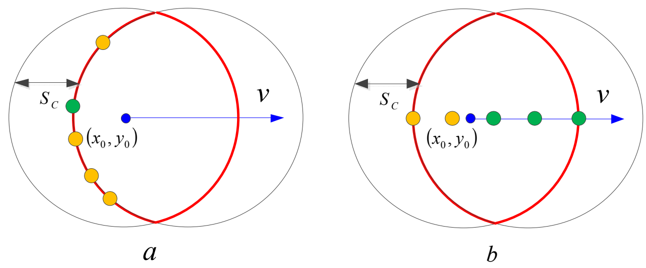

Figure 5. Various placement of nodes in a service area

Thus, the number of serviced nodes depends on the time of their stay in the area, i.e. of their position and order of service.

Suppose that in the sphere there are k - nodes, wherein the residence time of each of the equal

$$\hat{t}_i = \frac{r_i}{v} \qquad (2)$$

where r_i - the distance from the i - node to the border area.

Maintenance of each of them takes time τ_0. It is needed to select the order of service for which the number of served nodes is maximum. We assume that the service starts at time $t_1 = 0$, at the same time only one node can be served, start the service j-th node is equal to the account $t_j = (j-1) \cdot \tau_0$. To solve the problem it is needed to define a scheduling of the nodes at which it would be served by their maximum number. This problem can be solved by reducing it to the assignment problem. The solution of it takes time O (n^3) that is quite acceptable in the real world (for the actual number of nodes in the service area).

III. FUSN MODEL WITH UNKNOWN SENSOR NODES COORDINATE

When the coordinates are unknown, the input of the system receives a random stream of applications (nodes). The properties of this flow are determined by the properties of the sensor field (placing nodes on the surface), the radius of the service and the sUAV speed of its movement. We make the following assumptions:

-with sensory field is a Poisson field;

-consider that the sUAV is moving in a straight line at a constant speed V;

-zone service is a circle of radius R.

The distribution function of the incoming flow of requests

We will define the distribution function for the downstream applications. For this purpose we consider the service area of the sUAV at time 0 and time t. During the time t those applications (nodes) arrive that are in the area shown in fig. 6. According to the properties of the Poisson field, the probability that a certain area is n points (nodes) is determined by the Poisson distribution and depends only on the area of the field.

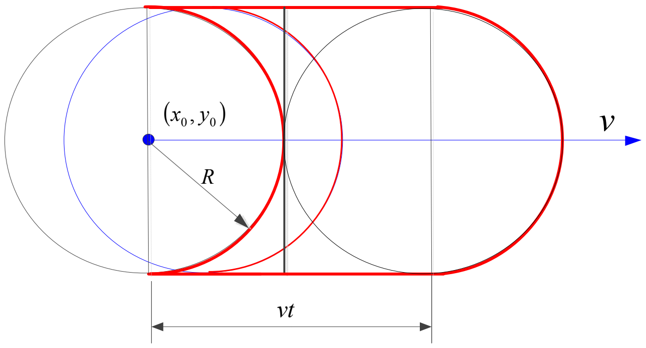

Figure 6. Probability of hitting n nodes in the area

The probability that S will be in m request (nodes) equals

$$p_m = \frac{a^m}{m!} e^{-a}, \qquad (3)$$

where $a = \rho \cdot S$;

ρ - the number of points (nodes) on a unit area;

$S(t)$ - area of the domain.

$$p_m(t) = \frac{(\rho \cdot S(t))^m}{m!} e^{-\rho \cdot S(t)}, \qquad (4)$$

Area of the domain shown in Fig. 6 is

$$S(t) = 2R \cdot vt \qquad (5)$$

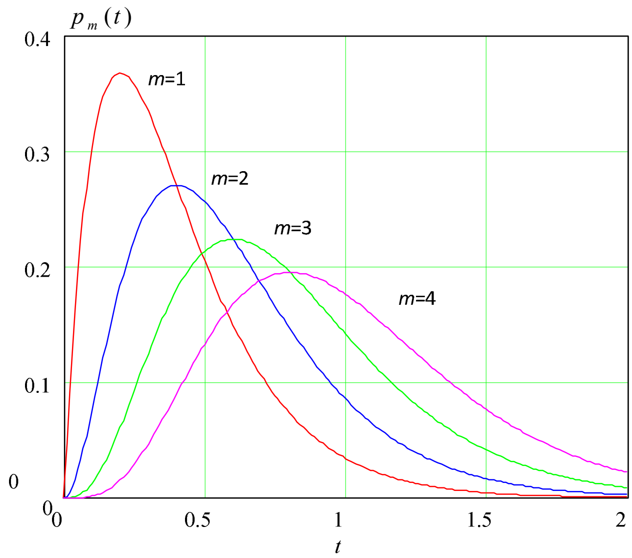

Figure 7. Accumulated distribution of number request

The flow rate, i.e. the average number of requests per unit of time equal to

$$\lambda = \rho \cdot 2R \cdot v \qquad (6)$$

The distribution of the time interval between request

Consider the random variable T - time interval between two successive events in the stream and find its distribution function.

$$F(t) = P(T < t) \qquad (7)$$

Then the probability that the length of time the area will go t m request

$$P(T \geq t) = 1 - F(t) \qquad (8)$$

Therefore, the probability can be calculated by the formula (3)

$$P(T \geq t) = p_0(t) = e^{-\rho \cdot 2R \cdot vt} \qquad (9)$$

Then the distribution function of the time interval between requests is (Fig. 8)

$$F(t) = 1 - e^{-\rho \cdot 2R \cdot vt} \qquad (10)$$

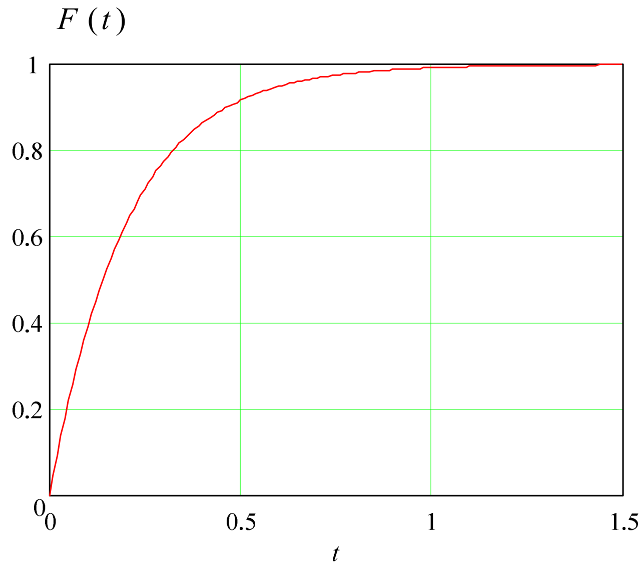

Figure 8. The distribution function of the time interval between request

Differentiating (10), we find the probability density (fig.9)

$$f(t) = 2\rho Rv \cdot e^{-\rho \cdot 2\rho Rv \cdot t} \qquad (11)$$

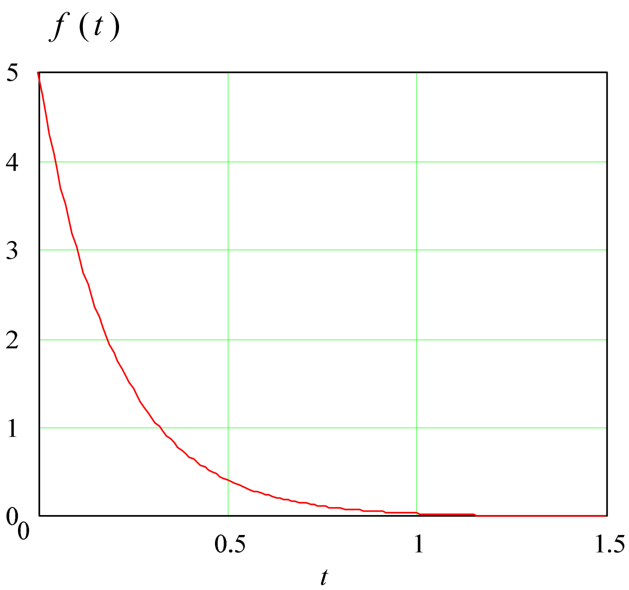

Figure 9. The probability density of the time interval between request

Thus, the input provides the elementary flow, the time intervals between the requests which are distributed according to the exponential distribution with the mean value

$$\bar{a} = \frac{1}{\rho \cdot 2R \cdot v} \qquad (12)$$

and variance

$$\sigma_a^2 = \frac{1}{4(\rho 2Rv)^2} \qquad (13)$$

Assuming that the residence time of the node in the service area is not limited, for estimation the amount of loss a known ratio can be applied

$$P = \frac{1-\rho}{1-\rho^{\frac{2}{C_a^2+C_b^2}K+1}} \rho^{\frac{2}{C_a^2+C_b^2}K} \qquad (14)$$

where $\rho = \frac{\lambda}{\mu} = \lambda \cdot t_0$;

C_a - coefficient of variation of the time interval between request;

C_b - coefficient of variation of the service time.

K – the number of cases in the waiting queue.

In this instance $C_a = 1$, a $C_b = 0$, with this in mind

$$P = \frac{1-\rho}{1-\rho^{2 \cdot K+1}} \rho^{2 \cdot K} \qquad (15)$$

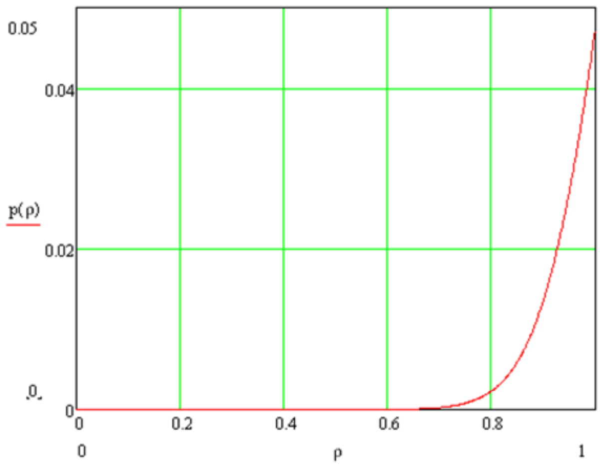

Figure 10. Impact of the sensors density on the losses

IV. Conclusions

The Ubiquitous Sensor Network (FUSN) is proposed as a new telecommunication network type. The FUSN structure example is considered. The two main FUSN models to data collection with known and unknown sensor nodes coordinates are investigated. The schedule collection procedure is proposed for the first model. The distribution function for requests number from sensor nodes is defined for the second model.

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