Power Optimization in Hybrid Localization Mechanism for Logistics Applications

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***Abstract* – Location-based services are widely used for logistics applications. But different localization methods have very different characteristics, and none of them works well under all conditions. In this paper, a system model of a hybrid and collaborative localization mechanism is proposed to provide location-based service for logistics applications. Based on the model, a centralized algorithm of the tracking devices is introduced. Then an optimization problem is formulated to minimize the power consumption of tracking devices in the hybrid mechanism. The computation result shows that the proposed hybrid mechanism outperforms any single localization.**

***Index terms* - location-based service; hybrid localization; power optimization**

I. Introduction

Location-based service has been of much interest in the field of mobile communications for many years, and different technologies provide a varying mix of resolution, accuracy, and power consumption. The well-known Global Positioning System (GPS) has the merits of all-weather, high-accuracy, and free access, but sometimes it does not satisfy the accuracy requirement in logistic applications since tracking devices often enter into an environment in which clear line-of-sights satellite signals cannot be received[2]. On the other hand, cellular positioning is superior to GPS technology in the aspect of improved urban canyon coverage, reduced time-to-first-fix (TTFF), and less battery drain. Although much effort has been put into the improvements of cellular positioning [3], the overall accuracy of this technique is inferior to GPS service; but, it provides a possible positioning method to track the position indoors. Also, Wi-Fi location tracking been developed for location services inside a building. It is primarily based on Received Signal Strength (RSS) matching, and much effort has been put into the RSS database construction, and accuracy improvement in fingerprinting techniques. Overall, applying Wi-Fi positioning into logistics tracking will increase the accuracy of tracking in indoor facilities, which is an urgent concern in the logistics field.

Since different location methods have their pros and cons, it is hard to decide on a single, especially when we try to achieve high accuracy and low power consumption at the same time. Therefore, a hybrid technique may be a feasible solution. [5] has provided a similar hybrid method in humanitarian logistics center management. It used a combination of RFID, sensor and network technologies to track the position of relief materials and equipment in natural disasters or other emergent situations. This hybrid method indeed provides an accurate positioning technique for the application in the humanitarian supply chain; however, in logistics field, sometimes goods may travel for a long time without any kind of charging or power injection. And we are also concerned about the economic cost of such tracking devices. Thus, power consumption, as well as the financial budget of the tracking system and devices will be an important consideration in logistics application.

In this paper we demonstrate a hybrid and collaborative mechanism for positioning and communication for logistics applications. A full-functional tag locates itself using a hybrid mechanism of GPS, GPRS, Wi-Fi, and Zigbee modules while a dummy tag does location tracking in a collaborative manner. An optimization problem is formulated on how to minimize the total power consumed by the clusters of full-functional tags. The rest of the paper is organized as follows. The system model is first presented in Section II. The optimization problem is formulated in Section III. Computation setup and numerical results are presented and discussed in Section IV. Finally, Section V draws the conclusion.

II. System Model

Fig. 1 shows the system model of the hybrid and collaborative tracking mechanism for logistics applications. Basically the system consists of a control center and various tags. Item tags are attached to the goods of which we need to know the location. Item tags report their location to the control center periodically with the help of operator tags, vehicle tags, and other infrastructures. Detailed assumptions and discussions are presented in the rest of this section.

A. Tags

There are three types of tags in the whole system, namely, item tags, operator tags, and vehicle tags, and all of them have limited battery power. However, vehicle tags and operator tags may be provided with large capacity batteries when compared to item tags, as they have easy access to battery chargers. So in our scenario, we do not care about

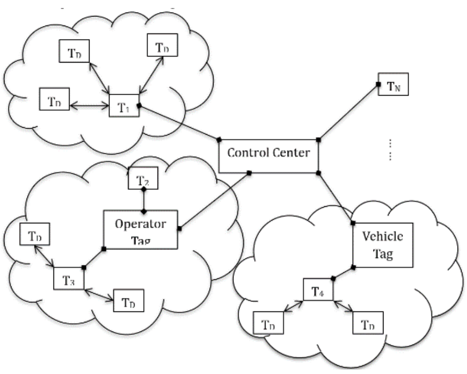

Fig. 1 System model

the power consumption of these two tags and focus our discussion in the power consumption of item tags.

There are two types of item tags, i.e. dummy tag and full functional tag. Dummy tags are also called Type 1 tags, noted as T_D in the system model. A dummy tag only has Zigbee module and motion sensor on it, and it uses the collaborative mechanism to do location tracking. Zigbee module is used to perform Zigbee neighborhood discovery periodically, say, every two hours to find whether there is any full functional item tag nearby. Then the dummy tag chooses the "best" full functional item tag T_i (the one with the most accurate location information), and transfers its identification info to T_i. T_i will transmit this dummy tag's info as well as its own identification info to the control center. The control center then considers that both tags share the same location info. The motion sensor in the dummy tag uses accelerometers (or G-sensors), and provides limited motion sensing functionality. If the motion sensor does not detect any movement for the past two hours, the tag does not need to update its location. But it still has to do Zigbee neighborhood discovery to detect which full functional tag it will make use of to transfer its ID info to the control center. Due to the comparatively low power consumption, we do not take into consideration the power consumed in the collaborative localization mechanism.

Full functional tags are also noted as Type 2 tags. Assume in our scenario that there are a total number of N full functional item tags controlled by the control center, denoted as $T = \{T_1, T_2, T_3 \ldots T_N\}$. A full functional tag has Zigbee, GPS, Wi-Fi and Cellular modules to perform localization; and for a single tag, it uses only one module to get its location. In the GPS module, we assume that the GPS receiver has a warm start in which the GPS chip retains in the memory the almanac so that the bootstrap and satellite detection will complete within less than 1 minute. And then the GPS antenna on the item tag receives and amplifies GPS signals. Afterward, the signal processor in the GPS module detects and tracks signals (PN codes) from individual satellites. Then the navigator processor calculates the position of the item tag. Cell-ID method is used in the cellular module of the item tag. The position of the target terminal is derived from the coordinates of the serving base station. Fingerprinting technique is used in the Wi-Fi module, in which the observed received signal strength (RSS) patterns received from several access points are compared with a table of predetermined RSS patterns

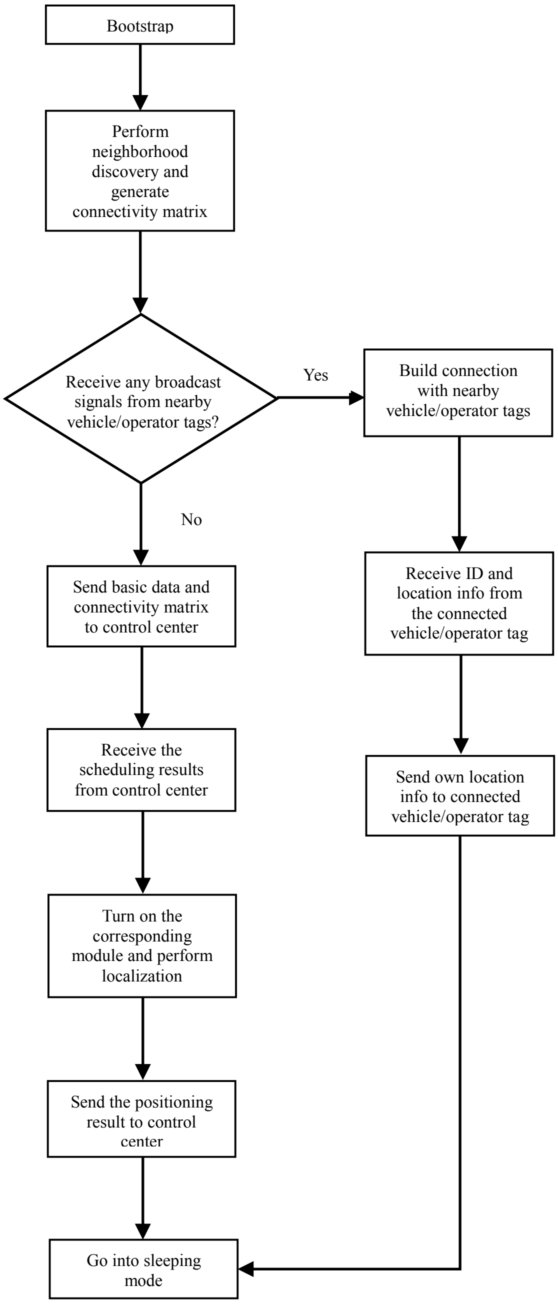

Fig. 2 Algorithm of a full functional tag

collected at various positions. And the position for which this comparison fits best is then adopted as the item's position.

Additionally, a motion sensor is attached in each full functional tag, as in a dummy tag. If the motion sensor does not detect any movement of the tag for the past two hours, then it does not need to perform locationing service nor update its location to the control center. (It saves energy in that it does not need to turn on any one of the location-tracking modules.) But the full functional tag needs to transfer its identification info as well as its dummy neighbors' to the control center, since its dummy neighbors need to update their locations under the help of a full functional tag. The location info of the dummy tag is the same as the location info in the last two-hour checkpoint of this full-function tag.

Assume all full functional tags have two modes: working mode and sleeping mode. A tag goes into working mode periodically, i.e. every two hours, and all full functional tags are synchronized so that they will enter the working mode within the same time period, or it may be woken up by the control center or other devices. Otherwise it stays in the sleeping mode to save energy. In the sleeping mode, none of GPS, Cellular, or Zigbee module is working.

Note that full functional tags have higher manufacturing, maintenance and operation costs compared with dummy tags. Thus, when a full functional tag has a low battery, say, 10 percent of full battery energy, it will notify the control center and turn down all its modules and GPRS connection with the control center after this checkpoint. Essentially it will act as a dummy unless it is recharged.

Fig.3 shows the algorithm of a typical full functional tag T_i in working mode.

Vehicle tags are attached on large vehicles, e.g. trucks, trains, and ships. GPS receiver and GPRS locationing device are attached on the tag to provide localization service. Communication with the control center is achieved via GPRS. Besides, a vehicle tag may act as a Wi-Fi access point to transmit its identification info and location info to full functional tags. In this way, full functional tags do not need to turn on its own location-tracking module to get its own position. They can get the identification info and the location info of the vehicle tags, and then send them to the control center as their location.

Operator tags are attached to staff (operator) in charge of goods with item tags. An operator will scan the item tags when he or she takes charge of them and when he or she has passed them to other operator or the system infrastructure. To locate itself, an operator tag may use Zigbee module, Wi-Fi receiver, or GPRS receiver. Connection to the control center is done with the help of GPRS system: a full functional tag may find the existence of an operator tag via Zigbee. This full functional tag will get the operator's identification info and takes the operator's location info as its own location, transmitting to the control center via GPRS.

B. Control Center

The control center communicates with full functional item tags via GPRS. Every time when item tags are going to update their location info, they first transmit basic data (i.e. tag ID, battery status, and etc.) to the control center. Then the control center types in these data into the centralized scheduling algorithm. This scheduling algorithm returns to the control center the results of which module each item tag T_i is going to use to update their location info. (Assume each tag will use only one module each time to do positioning tracking.) This scheduling result will be transmitted to the corresponding item tags via GPRS network. According to the scheduling result, each item tag will turn on the corresponding module to detect its location. And then each item tag sends back the positioning results to the control center via GPRS. Fig. 4 shows the algorithm of the control center.

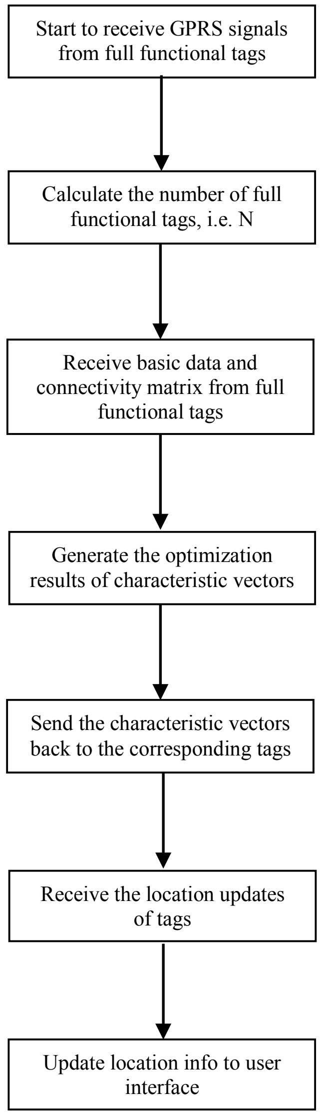

Fig. 3 Algorithm of control center

Also, sometimes we may want the updated location of a certain item tag T_i out of the regular two-hour checkpoint. In this case, the control center will first check whether T_i remains at the same position since last update by communicating with the tag which reported T_i's ID last time, either T_i itself, or some vehicle/operator tag. If not, then the control center will send broadcast signals containing the tag ID to all its tag members, i.e. full functional tags, vehicle tags, and operator tags. Vehicle and operator tags will then broadcast similar messages to all item tags they are in charge of. T_i will be woken up upon receiving the broadcast message. Then T_i will report its current location either with the help of nearby infrastructure or by self-location tracking.

C. Process Flow and Additional Assumptions on Infrastructure

Fig. 4 shows the typical process flow of a delivery tracking application system. Here we focus on how a full functional item tag makes use of different kinds of infrastructure to help them perform location tracking in

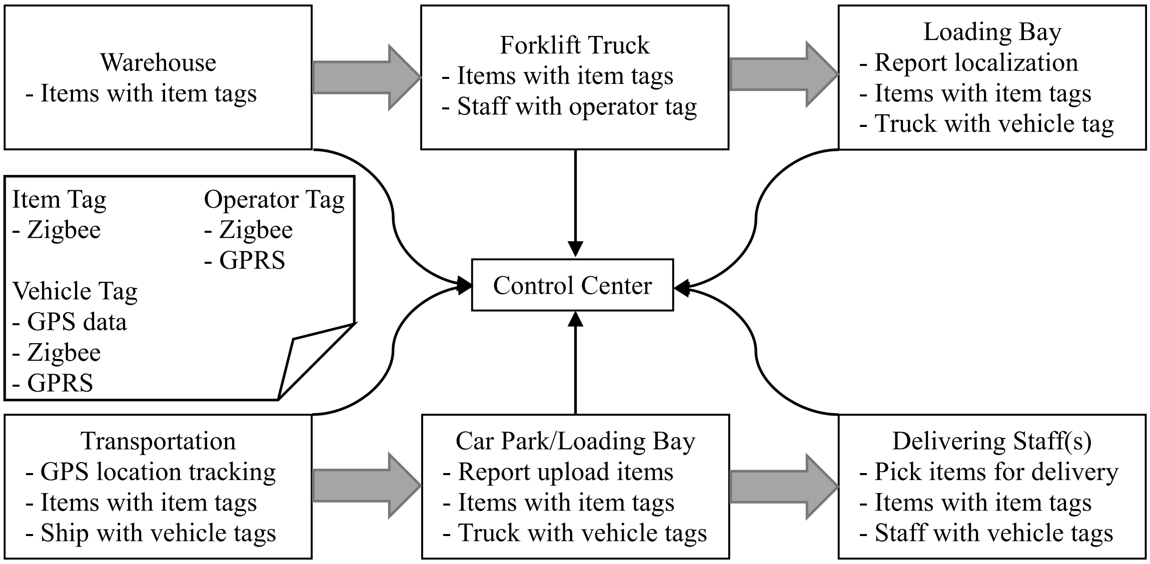

Fig. 4 Process flow of a deliver tracking application system

different stages, so that it can further decrease its energy consumption. The system structure is further expressed as follows.

In the warehouse stage, assume the warehouses are all implemented with Wi-Fi access points, and these APs have the connection to the database of the corresponding fingerprinting system. When a full functional item is in the warehouse, it will connect to the AP in the warehouse to perform location tracking. Note that it will not update its location info unless it is moved out of the warehouse.

Before an item tag is moved to or removed from a forklift truck, an operator tag will scan it, so that the item tag will use the same location info as the operator tag. Also, it will transmit the operator's identification info so that the control center knows it is in the charge of certain operators. Note that the operator tag will report location event every time it scans an item tag, and the control center will update the location info of the corresponding item tags.

In loading bay stage, item tags, as well as goods, are loaded to a large vehicle, mainly trucks, to be sent to the next infrastructure or vehicle. After the loading procedure, the vehicle tag will broadcast Wi-Fi signals to identify the full functional item tags on the truck. Once connected, the vehicle tag will send its identification info and as well as its location info to all its full functional neighbors. These item tags, as well as their dummy neighbors, will use the location info of the vehicle as their location, and sent it to the control center.

Delivering staff stage is similar to the forklift truck step. An item tag will make use of an operator tag to update its location info, and the operator tag needs to report location event when an item tag is scanned or removed from a certain operator.

III. Optimization Formulation

From the discussion of the previous section, we observe that the main power concern lies in the total power consumption of all the full functional item tags as the control center is assumed to be unlimited in energy and computational power. Also, the dummy tags consume a relatively fixed amount of energy every time it tries to update its location info. Thus, in this section, we focus on the formulation of an optimization problem on the total power consumption of the hybrid localization mechanism, i.e. full functional tags. In the Zigbee neighbor discovery process, each tag knows its neighbors and generates a connectivity matrix.

$$Z = \{Z(i,j), i,j = 1, \ldots, N\}$$

$$Z(i,j) = \begin{cases} 1, if\ tag\ Ti\ and\ Tj\ are\ connected \\ 0, \quad otherwise \end{cases}$$

The number of tags to which a single tag T_i is connected is called the degree of the tag T_i.

Then assume that the same module in different tags have the same working principle and energy consumption, i.e.

$$AE_k = T_k + C_k \quad k = 1,2,3,4$$

is the average energy consumption of GPS, Cellular, Wi-Fi, and Zigbee module, respectively.

T_k: energy consumption for transmission

C_k: energy consumption for computation

The energy consumption of tag Ti can be represented as

$$Ei = f(\overrightarrow{Xi}) = \{X_{i,1}, X_{i,2}, X_{i,3}, X_{i,4}\} \begin{Bmatrix} AE_1 \\ AE_2 \\ AE_3 \\ AE_4 \end{Bmatrix}$$

where

$$X_{i,1} = \begin{cases} 1, if\ GPS\ module\ of\ Ti\ is\ enabled \\ 0, otherwise \end{cases}$$

$$X_{i,2} = \begin{cases} 1, if\ GPRS\ module\ of\ Ti\ is\ enabled \\ 0, otherwise \end{cases}$$

$$X_{i,3} = \begin{cases} 1, if\ WiFi\ module\ of\ Ti\ is\ enabled \\ 0, otherwise \end{cases}$$

$$X_{i,4} = \begin{cases} 1, if\ Zigbee\ module\ of\ Ti\ is\ enabled \\ 0, otherwise \end{cases}$$

and the vector $\overrightarrow{Xi} = \{X_{i,1}, X_{i,2}, X_{i,3}, X_{i,4}\}$ is called the characteristic vector of tag T_i. Since we assume that one tag only has one module on at a time, then $\|\overrightarrow{Xi}\| = 1$.

The positioning uncertainty of GPS, GPRS, and Wi-Fi module is Δ_1, Δ_2, and Δ_3 respectively. The transmission range of Zigbee module is R_{Zigbee}. The positioning uncertainty of the tag T_i is remarked as $PUi = g(\overrightarrow{Xi}), i = 1,2, \ldots, N$

$$g(\overrightarrow{Xi}) = \begin{cases} \Delta j, & if\ X_{i,j} = 1, j \in \{1,2,3\} \\ R_{Zigbee} + \min g(\overrightarrow{X_k}), & if\ X_{i,j} = 1, j \in \{1,2\}, X_{i,4} = 1, Z(i,k) = 1 \end{cases}$$

The average positioning uncertainty of the system $\overline{PU}$ is calculated by averaging the positioning uncertainty of each tag as

$$\overline{PU} = \frac{1}{N}\sum_{1}^{N} PUi = \frac{1}{N}\sum_{1}^{N} g(\overrightarrow{Xi})$$

On the whole, we want to keep a single full functional item tag in view every two hours, as accurately as possible, and be kept informed of the update of every location event. Besides, all full functional item tags should have a total lifespan as long as possible, given a fixed battery capacity.

The objective of our optimization problem is to minimize the total energy consumed by all tags with constraints of guaranteeing the given requirement of positioning accuracy.

Objective function: $\min \sum_{1}^{N} Ei$

subject to $\overline{PU} \leq \Delta$

where Δ is threshold of the required system positioning accuracy.

IV. NUMERICAL RESULTS

A. Computation Setup

The summary of the models of four localization modules are listed in Fig. 5.

	Model	Voltage	Current	Power
Zigbee	JN5148 from JENNIC	3.3V	RX: 17.5mA TX: 15.0mA	RX: 57.75mW TX: 49.5mW
Wi-Fi	G2C547 Roving Networks	3.3V	RX: 39.4mA TX: 254.5mA	RX: 130mW TX: 840mW
GPS	LEA-6 GPS receiver u-blox	3V	Active: 40mA	120mW(max)
GPRS	LEON-G100 module u-blox	3.35-4.2V	Power off: <90 uA Idle: < 1.6mA GPRS class 10: < 410 mA	

Fig. 5 Models of four localization modules

The accuracy range of each module we used to solve the optimization problem is shown in Fig. 6.

Module	GPS	GPRS	Wi-Fi	Zigbee
Accuracy /Range	12.8m[5]	42.8m[6]	13m[7]	4m[8]

Fig. 6 Accuracy / range of four modules

We first fixed the accuracy range at 30m, and compute the power optimization as the number of tags change from 1 to 400. Then we decrease the accuracy range to 25m, 20m, 15m, 10m, and 5m to see the performance of our optimization problem.

B. Computation results

The computation results of 30m accuracy and 25m accuracy are presented in Fig. 7 and Fig. 8. Note that we only show the GPS positioning in the figure as other positioning methods share the same linear features as GPS positioning. From both figures we can see that the hybrid mechanism consumes a similar amount of power compared to GPS positioning if the system has a limited number of tags. But as the number of tags increases, the hybrid mechanism begins to outperform GPS positioning. When the number of tags are large enough, the total number of tags exercises little influence on the total power consumption. Or we can say that the total power consumption approaches an upper limit with the increase of tag quantities.

Fig. 9 shows the normalized power consumption of the hybrid mechanism with accuracy of 30 meters. In our assumption, every tag costs the same amount of energy doing GPS localization, and thus the normalized power consumption for GPS positioning is fixed. As expected, in the hybrid mechanism, the power consumption per tag at first increases with the increase of tag numbers. After reaching the peak at around 60 number of tags, the graph begins to fall. We can imagine that when we have a sufficient number of tags, the normalized power consumption approaches zero. Also, when the requirement of accuracy varies, we will get graphs with similar features. So such figures are omitted here.

From another point of view, Fig. 10 and Fig. 11 compare the total and normalized power consumption of systems with different number of tags, i.e. N=50 and N=20. When the requirement of accuracy decreases, the total power consumption falls as expected. Additionally, the total number of tags has less influence on the total power consumption as the accuracy decreases. It means that the system consumes similar amount of power when we do not need so accurate results, regardless of the number of tags.

V. CONCLUSION

A system model for a hybrid and collaborative localization mechanism for logistics applications is proposed. Focused on the power consumption of the hybrid localization mechanism, an integer linear optimization problem is introduced. Our computation result shows that the hybrid localization mechanism outperforms any single positioning method when the number of tags are sufficiently large. Further work may focus on the improvement of the system model by introducing a decentralized algorithm.

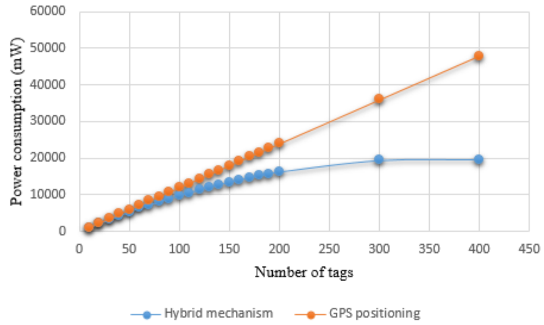

Fig. 7 Total power consumption with accuracy requirement of 30 m

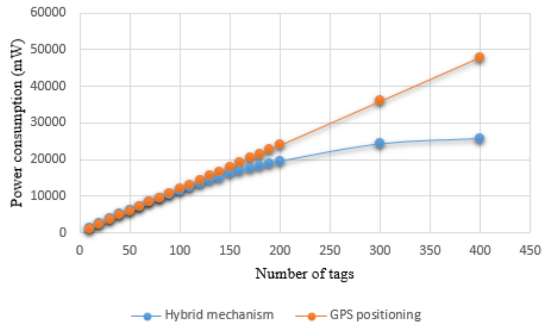

Fig. 8 Total power consumption with accuracy requirement of 25 m

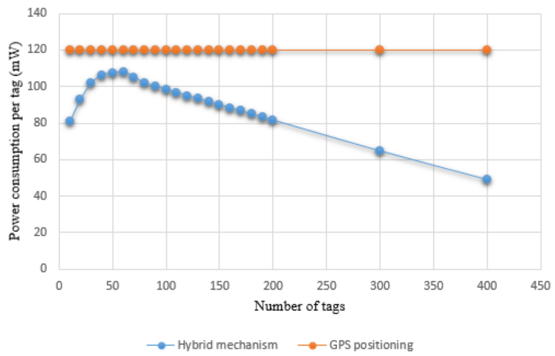

Fig. 9 Power consumption per tag with accuracy requirement of 30 m

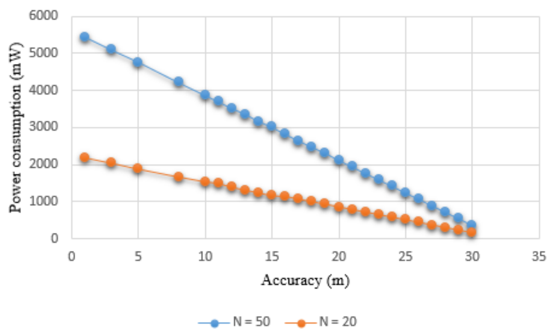

Fig. 10 Total power consumption with different number of tags

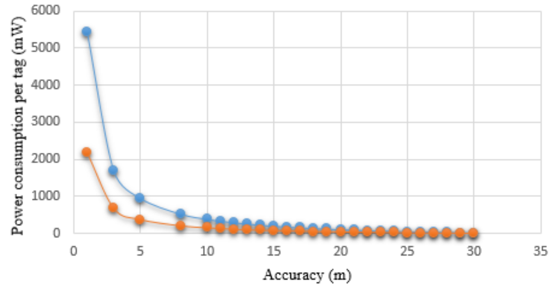

Fig. 11 Normalized power consumption with different number of tags

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