An energy-efficient MAC Protocol for Real-time Target Tracking System Using Wireless Sensor Network

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Abstract **- Target tracking systems using wireless sensor networks have been used in many application domain such as battlefield surveillance, wildlife monitoring and border security. These applications need to meet certain real-time constraints in response to transient events, such as fast-moving targets or real-time property should be considered as the most important requirement of the tracking system. In this paper, we develop a real-time target tracking system that utilizes the Lateration method (for localization) and the event-driven routing protocol EMRP (for reporting) running over an energy-efficient MAC protocol. The performance of collaborative tracking system in term of energy consumption, tracking delay, and trajectory accuracy is evaluated in extensive computer simulation. The results show that our method achieves better energy consumption while maintaining a reasonable accuracy of tracking performance and achieving real-time requirement.**

Keywords - Target Tracking, Estimation, Lateration, Wireless Sensor Networks.

I. INTRODUCTION

Tracking algorithms for wireless sensor networks (WSNs) are expected to serve as a key infrastructure for variety of domains, such as robotics [1,2], vehicular traffic [3], surveillance [4], battle field monitoring and military intrusion detection [5]. The purpose of these applications is to obtain a record of the trajectory of moving targets on a near-continuous basis over space and time by processing the sensing data. Considering the resource constraints of sensor hardware and the uncertain behavior of targets, this goal is hard to achieve without trading off the *accuracy* in tracking performance and the *lifetime* of applications, in particular, the *energy consumption*.

In addition, most of these tracking applications deal with various kinds of *real-time* constraints in response to the physical world. For example, surveillance may require a sensor node to detect and classify a fast moving target within *1 second* before it moves out of the sensing range [6]. Compared with traditional distributed systems, the real-time guarantee for sensor networks is more challenging due to the following reasons. First, sensor networks directly interact with the real world, in which the physical events may exhibit unpredictable spatio-temporal properties. These properties are hard to characterize with traditional methods. Second, although the real-time performance is a key concern, it should be performance compatible with many other critical issues such as energy efficiency and system robustness. For example, it is not efficient to activate the sensors all the time only for the benefit of a fast response; the naive approach severely reduces the system lifetime. Third, the resource constraints restrict the design space we could tradeoff.

All these issues challenge us the following question: how to design a target tracking system that contributes to not only energy efficiency of sensor nodes but also tracking accuracy in real-time? The main contributions of our work can be summarized as follows:

(1) We exploit and utilize the novel Lateration localizing scheme, this is a part of our research published in [7], to estimate the trajectory of a dynamic target. The estimation contains the location of the target and its moving direction. Then, based on the estimation results, an energy-efficient and real-time MAC protocol is proposed by reducing the number of proactively awakened nodes and controlling their active time in an integrated manner with limited loss on the tracking performance.
(2) The event-driven routing protocol (EMRP algorithm) is implemented overlay the proposed MAC protocol in order to construct a route for transmitting the estimated data to the Base Station (BS). These techniques allow system to track the target with lowest

energy consumption, especially prevent some certain nodes over consuming energy, while maintain low missing-rate, thus prolong the lifetime of the whole sensor network.

(3) All the algorithms are distributed which can run on individual nodes and do not require global information of the network. This will improve the scalability of tracking system for large-scale WSNs.

(4) We analyze all delay components that contribute to the end-to-end delay of the system. The analysis is verified in the extensive simulation.

(5) We also implement our system in simulation and compare with EKF method. The performance of collaborative tracking system in term of energy consumption, tracking delay, and trajectory accuracy is evaluated. The simulation results show that the new method achieves better energy consumption while maintaining a reasonable accuracy of tracking performance.

The remainder of this article is organized as follows: Section 2 discusses the related work. Section 3 describes components of a target tracking system while Section 4 presents an overview of MAC schemes design for our system, describes the operation of medium access control used, and analyzes the end-to-end-delay. We also evaluate the tracking accuracy, energy-efficiency, and end-to end delay of the system through simulation and presents result in section 5. Finally, the last section summarizes the conclusion and future work.

II. Related Work

Moving object tracking using WSN has received considerable attention in recent years and intended solutions can be mainly classified into two schemes, which are: *tree-based tracking* and *cluster-based tracking*. Tree-based schemes organize a structured tree for transmitting tracked data to the BS while cluster-based solution form one or many clusters represented by Cluster Heads (CHs) and these CHs are responsible to collect tracked data from non-CH members and then to construct a route in order to transmit data to the BS.

In *tree-based target tracking*, while tracking a target the nodes that detect the target communicates with each other and selects a root node. The root node collects information from all the nodes via a distributed spanning tree. If the root node is far away from the target, then the tree will be reconfigured. Although the spanning tree based approaches track the moving objects more accurately, tree organizations result in high-energy consumptions. Examples of tree-based tracking methods include heuristic object tracking algorithm [8] that uses a Langarian Relaxation (LR) based approach though minimizing total communication cost of object tracking tree, but the algorithm is not scalable enough and needs to be modified for measuring tracking accuracy. DOT [9], a unique protocol reports the tracking information of moving object to moving source by using Gabriel Graph (GG). In Scalable Tracking Using Networked sensors (STUN) [10], the link cost (between two nodes) of the tree route (called DAB-Drain and Balance tree) is calculated by Euclidean distance. However, STUN has two drawbacks. First, DAB tree does not replicate physical sensor network as it is a logical tree, hence an edge may consist of multiple communication hops and may raise communication cost. Second, the construction of DAB tree does not consider query cost. Presented in [11] is a network aggregation model by organizing a logical tree called Deviation Avoidance Tree (DAT) that considers physical topology of the network, thus reducing the total communication cost. The location update part is an extension of the work [10]. Although the spanning tree based approaches track the moving objects more accurately, a tree organization result in high-energy consumptions and also increases the complexity of algorithm.

In order to exchange information of tracking object to the BS, a *cluster-based tracking system* divides nodes into different clusters statistically or dynamically, each is represented by a Cluster Head (CH). CHs are responsible to collect tracked object information and send to the BS. *Statistical approach* forms clusters at the time of network deployment and the properties of each cluster are fixed such as number of members, area covered, etc. Obviously, it is a simple method but cannot adapt well to the conditions of a moving target. Examples of static cluster schemes are RARE-Area and RARE-Node in [12]. In contrast to static scheme, *dynamic cluster* architecture has several desirable features. When a sensor with sufficient battery and computational power detects signals of interest, it volunteers to act as a CH. Compared with the static clustering approaches, dynamic clustering networked sensors do not statically belong to a cluster and may support different clusters at different times. Moreover, as only one cluster is active in the vicinity of a target with high probability, redundant data is suppressed and potential interference and contention at the MAC level is mitigated. We realize that many static and dynamic cluster-based tracking systems are developed and dynamic schemes outperform static schemes because of its energy efficiencies and flexibility. Dynamic schemes, such as DELTA [13], form cluster dynamically according to different criteria, thus can adapt better to the change of a moving targets but these solutions also have their own weakness: DELTA can track only a person with constant speed. Furthermore, all existed dynamic cluster scheme concentrate only at each side of a tracking system, but they could not give an overall tradeoff between tracking accuracy, energy efficiency and real-time, especially analyzing the end-to-end delay achieved by the system.

III. Real-time Target Tracking System

Generally, there are three common procedures when design a dynamic cluster target tracking system (that can provide energy efficiency, reasonable tracking accuracy and real time) regardless of various types of target and tracking environments.

1. Target Detection

In a typical target tracking scenario, a moving target tends to occur randomly and occasionally. Continuous activation of sensor nodes in this case wastes a significant amount of energy, and therefore all sensor nodes are designed to cyclical turn off their radio transmission or going into inactive stage in the absence of a target. Each node is scheduled in inactive stage for the period T. A duty cycling β with $(0 \leq \beta \leq 1)$ is defined as a probability of a node being awakened within period T. To reduce missing detection, each node chooses a wakeup point T_{start} independently and evenly distributed between 0 and T. The node performs sensing in an interval time βT and back to inactive stage until the next duty cycle. Within the duty cycle, if the acoustic power intensity value emitted from the target at a particular acoustic sensor exceeds the predetermined threshold, this sensor determines that a target is in the network. Then the detected sensor broadcasts an alarm message to proactively awaken its neighbor nodes to prepare for the approaching target. The relationship between the radio transmission range and the acoustic signal detection range determines the number of awakened nodes. The radio transmission range is controlled by adjusting the transmission power, while the acoustic signal detection range is controlled by adjusting the detection threshold.

2. Target State Estimation and Prediction

The second procedure is to localize the position of targets or sensors should be localized prior to participating in target tracking tasks: localization mission.

Many location techniques have been emphasized in the literature. If the targets are friendly and able to communicate with sensors, the localization mission becomes easier and the same technique with sensor network localization can be used. Unfortunately, such cases are often very limited. In general, targets are not cooperative with sensors, such as enemy vehicles and unregistered victims in disaster areas. In order to overcome this problem, many estimation and also prediction algorithms have been suggested such as Bayesian [14] and Kalman filtering method [15] in the literature. The Kalman filter (KF) is a classical method that can estimate the original state of target by collecting and analyzing a number of sensing data. In addition, this filter can also predict the movement of target in the near future. A great challenge is how to coordinate a randomly deployed large-scale network to efficiently track a moving target, when the target state changes dynamically under uncertain conditions due to the noise of error measurements, while conserving network resources and dealing with sensor hardware constraints. For linear model with Gaussian noise, the optimal solution is the KF [15]. For nonlinear models, variations of KF such as the extended Kalman filter (EKF) [16] have also been developed to estimate the target state. In this state, we exploit and utilize the novel Lateration localizing scheme to estimate and predict the trajectory of a dynamic target.

Lateration [17] is a classical algorithm that can be used to calculate the coordinates of the object if positions of several sensors are known a priori, as well as the distance to them. In this paper we denote $(x(k), y(k))$ as coordinates of the target at timestep k while (x_i, y_i) is the coordinates of sensor i. Let $r_i(k)$ be the precise distance between the unknown position and each sensor. From Pythagorean Theorem, we obtain a system of three equations as follows:

$$r_i(k) = \sqrt{(x_i - x(k))^2 + (y_i - y(k))^2}. \quad (1)$$

If the coordinates of at least three sensors are known a priori $(i = 1,2,3)$, the coordinate $(x(k), y(k))$ of the target can be obtained through the following equations:

$$\begin{cases}(x_1 - x(k))^2 + (y_1 - y(k))^2 = r_1^2(k) \\ (x_2 - x(k))^2 + (y_2 - y(k))^2 = r_2^2(k) \\ (x_3 - x(k))^2 + (y_3 - y(k))^2 = r_3^2(k)\end{cases} \quad (2)$$

The equations (2) can be rewritten in a matrix form:

$$2\begin{bmatrix} x_3 - x_1 & y_3 - y_1 \\ x_3 - x_2 & y_3 - y_2 \end{bmatrix}\begin{bmatrix} x(k) \\ y(k) \end{bmatrix} = \begin{bmatrix} (r_1^2(k) - r_3^2(k)) - (x_1^2 - x_3^2) - (y_1^2 - y_3^2) \\ (r_2^2(k) - r_3^2(k)) - (x_2^2 - x_3^2) - (y_2^2 - y_3^2) \end{bmatrix} \quad (3)$$

In reality, the range measurements are not perfect and contain some errors. To take this measurement error into account, we can represent the imprecise range measurement in the form $\tilde{r}_i(k) = r_i(k) + v_i(k)$ where $r_i(k)$ represents a perfect measurement and $v_i(k)$ is an unknown measurement error at time step k. In this case, solving the system for trilateration does not always give an exact solution. In fact, it is possible that three circles are intersecting in more than three points. Therefore, more than three sensors are used resulting in an overdetermined system of equations to take into account individual measurement errors. This overdetermined system of equations can be written in a matrix form as follows:

$$2\begin{bmatrix} x_n - x_1 & y_n - y_1 \\ \vdots & \vdots \\ x_n - x_{n-1} & y_n - y_{n-1} \end{bmatrix}\begin{bmatrix} x(k) \\ y(k) \end{bmatrix} = \begin{bmatrix} (\tilde{r}_1^2(k) - \tilde{r}_n^2(k)) - (x_1^2 - x_n^2) - (y_1^2 - y_n^2) \\ \vdots \\ (\tilde{r}_{n-1}^2(k) - \tilde{r}_n^2(k)) - (x_{n-1}^2 - x_n^2) - (y_{n-1}^2 - y_n^2) \end{bmatrix} \quad (4)$$

For this overdetermined system of equations, a solution can be computed by minimizing the mean square error $||\boldsymbol{A}\boldsymbol{x} - \boldsymbol{b}||^2$, where $0.5\boldsymbol{A}$ is the left-hand matrix, $\boldsymbol{x} = (x(k), y(k))$ is the vector describing unknown target and $\boldsymbol{b}$ is right hand side vector of equation. The term $||\boldsymbol{A}\boldsymbol{x} - \boldsymbol{b}||^2$ is the Euclidean norm squared of the residual $\boldsymbol{A}\boldsymbol{x} - \boldsymbol{b}$, which is equal to:

$$\begin{aligned} ||\boldsymbol{A}\boldsymbol{x} - \boldsymbol{b}||^2 &= (\boldsymbol{A}\boldsymbol{x} - \boldsymbol{b})^{\mathrm{T}}(\boldsymbol{A}\boldsymbol{x} - \boldsymbol{b}) \\ &= \boldsymbol{x}^{\mathrm{T}}\boldsymbol{A}^{\mathrm{T}}\boldsymbol{A}\boldsymbol{x} - 2\boldsymbol{x}^{\mathrm{T}}\boldsymbol{A}^{\mathrm{T}}\boldsymbol{b} + \boldsymbol{b}^{\mathrm{T}}\boldsymbol{b}, \end{aligned} \quad (5)$$

where $(\boldsymbol{A}\boldsymbol{x} - \boldsymbol{b})^{\mathrm{T}}$ is the transpose of the matrix $(\boldsymbol{A}\boldsymbol{x} - \boldsymbol{b})$. Regarding the above equation as a function of **x**, minimizing this expression means that the gradient of this function should be set equal to zero, which leads to $2\boldsymbol{A}^{\mathrm{T}\boldsymbol{A}\boldsymbol{x}-2\boldsymbol{A}^{\mathrm{T}\boldsymbol{b}=0}}$. This is equivalent to $\boldsymbol{A}^{\mathrm{T}\boldsymbol{A}\boldsymbol{x}=\boldsymbol{A}^{\mathrm{T}\boldsymbol{b}}}$. This equation is called the normal equation for the linear square problem. The coordinates of target is estimated via the following equations:

$$\boldsymbol{x} = (\boldsymbol{A}^{\mathrm{T}}\boldsymbol{A})^{-1}\boldsymbol{A}^{\mathrm{T}}\boldsymbol{b}, \quad (6)$$

where $(\boldsymbol{A}^{\mathrm{T}}\boldsymbol{A})^{-1}$ is the inverse matrix of $(\boldsymbol{A}^{\mathrm{T}}\boldsymbol{A})$.

3.Tracking and Updating

After estimating and predicting the position and movement of target, sensing information collected from different sensors in WSNs may be redundant. Furthermore, in a typical target tracking scenario, a moving target tends to occur randomly and occasionally, and only the sensors near the target can detect and perform sensing it. Thus the second problem that we need to consider is the collaborative data processing among sensor nodes (a tracking cluster with a cluster head - CH) that are waken up for detecting object. For a case of dynamic cluster tracking system that divides networks into different clusters, this collaborative data processing need to be designed carefully within each cluster in order to minimize the control information exchanged between sensors while still maintaining reasonable tracking accuracy and real-time.

The CH predicts the next expected target approaching area. If the measurement signal falls below the user-predefined threshold, the CH sends an activation message to awake the next suitable sensors corresponding to the estimated approaching target. The pseudo-code of the algorithm for tracking and updating is presented in Algorithm 1.

Algorithm 1 Tracking and Estimation

Require: measurement from S_g : $\{\tilde{r}_1(k), \tilde{r}_2(k), \ldots \tilde{r}_n(k)\}$ and coordinates (x_i, y_i) of sensor i with $i = 1, 2, ..., n$ $(n \geq 3)$
Ensure: obtain trajectory of target
for each time step k **do**
    estimate trajectory of target based on Eq. (6)
    send state of target to BS
end for

4. Target State Reporting

After aggregating data from all non-CH members, CHs in its turns also need to construct a route for transmitting this data to the base station (BS) so that the BS can track the movement of the target. This procedure can be realized by a routing protocol and if desired appropriately, it can lead to energy saving. In this work, we utilize EMRP [18] routing protocols to report tracking data from the CH to the BS in a multi-hop relay manner. The following subsections present briefly operation of the routing protocols.

The EMRP is used for starting the routing process from CH to the BS. If CH is in transmitting range with BS, it will send data directly to BS. Otherwise CH will start to find a relay node toward BS by broadcasting a

REQ_RELAY message to all one-hop neighbors. The REQ_RELAY packet contains node's ID, residual energy, and location to BS to its neighbors. Each node (except node which has direct communication with BS) then uses this information to choose a relay node and a backup node according a link cost function F_{RN} based on as follows:

$$F_{RN}(j) = E_{res}(j) * \frac{1}{d(j,BS)} * cos\alpha_j$$

$$Max\ F_{RN}(j) \xrightarrow{\forall j\in Y} \text{Relay Node} \qquad (7)$$

$$SecondMax\ F_{RN}(j) \xrightarrow{\forall j\in Y} \text{BackupNode}$$

The $cos\alpha_j$ with the α_j is the critical angle value created by node j, the clusterhead, and the base station, can be obtained by the following geometric calculation:

$$\cos\ \alpha_j = \frac{d(CH,j)^2 + d(CH,BS)^2 - d(j,BS)^2}{2d(CH,j)d(CH,BS)} \qquad (8)$$

where $E_{res}(j)$ is energy available of node j, $d(j,BS)$ is the distance from the candidate node j to the BS, $d(CH,j)$ is the distance from CH to j, $d(CH,BS)$ is the distance from the clusterhead to the base station.

The node that has the maximum value of $F_{RN}(j)$ is selected as the relay node RN_1, and the second one is selected as the backup node BN_2. The CH stores value of residual energy of RN_1 and BN_1 to control their role. After the initializing stage, we have a meshed hierarchy network topology. In the next hop, the relay node in turn serves as the CH using the same method to relay data to the next relay node, backup node and switch dynamically between them by control the residual energy of the relay node and backup node. This process is repeated until data frames reaching to the BS. Because of the energy monitoring method, each node is always aware of its relay node's and backup node's energy level and will replace them with new nodes if their energy falls below the critical level. Thus it eliminates the chance a node keeps sending data messages to its relay node when the relay node is already run out of energy, and hence improves the reliability and fault-tolerance of the event-driven cluster-based protocol. Moreover, the dynamic switch between relay node and backup node can reduce the energy consumption deviation of nodes along the transmission paths and achieve better load-balance compared to other event-driven cluster-based protocols. Details of the EMRP algorithm can be found in [18].

5. Underlay MAC Protocol for Target Tracking System

The real time property of a system depends not only on routing scheme implemented, but also on the effectiveness of the low level MAC layer that is responsible for sharing the transmission medium. In other words, MAC protocol plays an important role for assuring real-time characteristic of target tracking application. That is why it is necessary to investigate the MAC protocol for general WSN, and also for our target tracking WSN. Therefore, in order to be able to evaluate the end-to-end delay of the system, we propose an *unslotted* and *unbeaconed* energy-efficient MAC protocol as an underlying MAC for the real-time target tracking system with Lateration *localizing* scheme and *cluster-based* and *event-driven* routing algorithm EMRP. The following section presents the details of the MAC protocol.

IV. MAC PROTOCOL

1. MAC Requirements for Traditional WSN

In any wireless networks, its smooth operation depends, not only on routing scheme, but also on the effectiveness of the low-level Medium Access Control. For designing an effective MAC protocol of a traditional WSN, it is important to minimize the following sources of overhead as well:

- *Collisions*: if two nodes transmit at the same time and interfere with each other transmission, packets are corrupted. Hence, the time and energy used during transmission and reception are wasted;
- *Protocol overhead*: most MAC protocols require control packets to be exchanged. Since these packets contain no application data, we consider their transmission and reception as overhead.
- *Overhearing*: since the ether is a shared medium, a node may receive packets that are not destined for it; it could then as well have turned off its radio to save energy.

In traditional wireless sensor networks, MAC protocol has been extensively studied. There are two different types of MAC protocols: the fixed assignment channel access method which assign nodes onto different sub-channels to avoid collision (TDMA), and the contention-based channel access method in which nodes compete for the wireless communication channel, example include carrier sense multiple access (CSMA).

2.MAC Requirements for Target Tracking WSN

Target tracking WSN differs in general from traditional WSN that transmits voice or data and its MAC scheme also carries its own characteristics:

- Most of the time nodes do not need to communicate, because targets seldom occur.
- When observing a physical event, nodes communicate with their direct neighbors to filter out erroneous sensors readings and increase knowledge, before jointly reporting an event.
- Target trajectory information is reported to BS acting as a bridge to fixed infrastructure.
- Reliability.

These characteristics imply that the target tracking sensor network is usually empty, and that communication is highly structures: towards the BS and between direct neighbors. In addition, typical messages are small (approximately 100 bytes) since the in-network processing allows for reporting concise information instead of raw sensor readings. This one direction feature of traffic in our target tracking WSN leads to the reduced numbers of packets overhearing. More concretely, in EMRP protocol, traffic is only towards BS and between direct neighbors. In addition, data rate is low and message size is short. These features of EMRP lead to the low possibility of collision. This observation in our tracking system plays an important role on the design of the MAC protocol. Instead of optimizing for avoiding overhearing, MAC protocol for target tracking sensor networks that works at low data rate must first and foremost be collision free, energy efficient, reliability and also real-time (as described previously). Consequently, they should be optimized for the case that there is little or no network traffic.

We realize that for target tracking application, TDMA-based protocols, in contrast to contention-based protocols, are very effective at avoiding collisions. They require, however, some authority to orchestrate activities within networks. This complicates their deployment in our multi-hop sensor networks where nodes are equal and have limited resources. That is why, the selection of contention-based protocol is chosen in our system due to its light overhead and simplicity.

3. Description of IEEE 802.15.4

The IEEE 802.15.4 standard [19] is designed as a low power and low data rate protocol offering high reliable protocol for wireless connectivity among inexpensive, fixed and portable devices such as sensor network. It both defines the physical layer and the medium access layer. For the physical layer, 27 communication channels in three different frequency ranges are defined in the industrial scientific medical (ISM) band: 16 channels in the 2.4 GHz band, 10 channels at 915 MHz and 1 channel at 868 MHz. The 2.4 GHz band is available worldwide and operates at a raw data rate of 250 kbps. The channel of 868 MHz is specified for operation in Europe with a raw data rate of 20 kbps. For North America the 915 MHz band is used at a raw data rate of 40 kbps. All of these channels use DSSS. The standard further specifies that each device shall be capable of transmitting at least 1 mW (0 dBm), but actual transmit power may be lower or higher. Typical devices are expected to cover a 10-20 m range.

The IEEE 802.15.4 network operates either in a beaconed and un-beaconed version [20]. In the beaconless mode, a simple CSMA/CA protocol is used. When a device wishes to transmit data, the device waits for a random number of back off periods. Subsequently, it checks if the medium is idle. If so, the data is transmitted, if not, the device backs off once again and so on. The beaconed mode uses a super-frame structure. A super-frame starts with beacons sent by a dedicated device, called a coordinator, at predetermined intervals ranging from 15 ms to 251 s. The time between these beacons is split in an active and inactive period. In the inactive period, the device enters a low power mode during which no radio traffic is allowed. Communication between the devices only takes place in the active period. By changing the duration of the active and inactive period, the network can operate under low duty cycle to save energy.

We realize that in this beaconed mode, it is necessary to have a special signal to synchronize all nodes in the network and this mission is not a straightforward task in a large target tracking network with thousands nodes. In addition, tracking application does not need to implement special time slot for guaranteed QoS. That is why beaconed mode is not appropriate for our system. In the following, we analyze the operation of unslotted and unbeaconed mode of 802.15.4:

4. Unslotted and Unbeaconed CSMA/CA mode

The unslotted CSMA/CA algorithm is represented in Fig. 1 [19] and Fig. 2. Before accessing the channel, the device must wait for a random backoff interval defined in the interval from 0 to (2BE – 1) backoff periods, where BE, the backoff exponent, initially takes the value *macMinBE* and one backoff period is equal to *aUnitBackoffPeriod* symbols. After that, if the clear channel assessment (CCA) function indicates that the channel is idle, the device starts its transmission after a turnaround time delay, which is the time necessary to for the radio transceiver to switch from receive state to the transmit state. If the channel is busy, the device defers its transmission and increments NB, the number of transmission attempts for the current packet. BE is also incremented if it has not reached its maximum value, *aMaxBE*. If the maximum number of transmission attempts, *macMaxCSMAbackoffs*, was not reached, a new backoff interval is determined; otherwise, the algorithm declares a channel access failure.

The values of the unslotted CSMA/CA parameters are specified in Table 1.

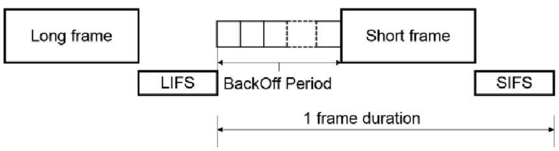

Figure 1. Frame sequence in IEEE 802.15.4

Table 1. IEEE 802.15.4 Parameters

Parameters	Values	Description
macMinBE	[0-3], default = 3	The minimum value of the backoff exponent
aUnitBackoffPeriod	20 SP	The length of the backoff period, where the symbol period (SP) is 16 µs
aMaxBE	5	The maximum value of the backoff exponent
macMaxCSMAbackoffs	[0-5], default = 4	The maximum number of backoff periods

The transmitted frames are followed by an Inter Frame Space (IFS) in order to allow the MAC layer a finite amount of time to process data received from the PHY. Before starting the back off period, the device will wait one IFS. Long frames are followed by a Long IFS (LIFS) and short frames by a Short IFS (SIFS). An example of a frame sequence, using acknowledgments (ACKs), is given in Fig. 1. If no ACKS are used, the IFS follows the frame immediately.

5. End-to-End Delay Analysis

In this section, we give a brief overview for tracking operation in our system that uses Lateration and EMRP routing method. After a target enters the area, it activates the first sensor node that can confirm the detection, then other nodes nearby are awakened to form a cluster to deliver the aggregated reports to the base (according the operation of EMRP). More specifically, in our system this tracking operation has seven phases. Each phase contributes a sub-delay component to the total end-to-end delay. The analysis is verified in the extensive simulation presented in Section 5.

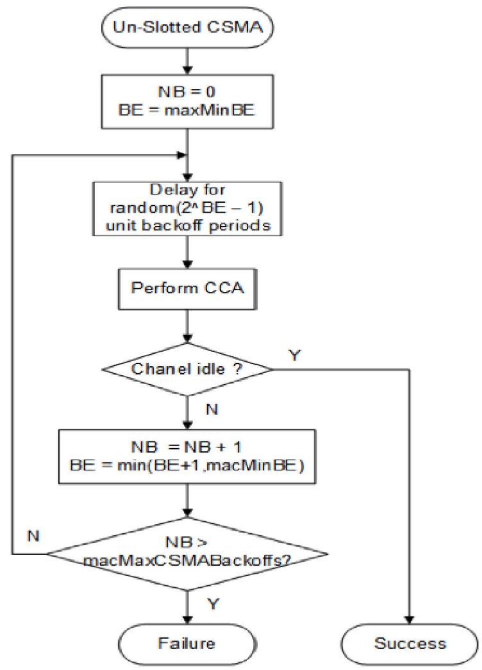

Figure 2. Unslotted CSMA/CA mode

The operation of our tracking system includes five phases. Each phase contributes a sub-delay component to the total end-to-end delay:

- **Initial activation phase:** An initial activation delay, denote as $T_{initial}$, is the period before the first active node starts to sense the incoming target. If sensors are activated by CH for ensuring tracking coverage, the $T_{initial} = 0$. Otherwise, $T_{initial} = T_{start}$.
- **Initial Target Detection phase:** After the initial activation, it takes a certain delay, defined as T_{detect}, for the first active node to confirm the detection. Specifically, T_{detect} is the period of time for a detection algorithmto recognize a target signature. Multiple reasons contribute to this delay. First, the sensor hardware has a response delay for the physical signals that the target generates. Second, the sensing circuitry requires special operations with a further delay. Third, the sampling is discrete and periodic, not continuous,

which leads to sampling delay. Fourth, the target signature itself may be time related (e.g., a certain frequency), which cannot be recognized from just one sample.

- **Cluster formation phase:** Once awakened, all nodes that detect the same target join a cluster. Each cluster is represented by a CH to maintain operation of the cluster. We denote $T_{cluster}$ as a time value for the cluster formation.
- **Data aggregation phase:** The CH gathers measurements from its member and executes tracking algorithm to track the target and then report to the BS. We use $T_{process}$ to denote the cluster aggregation delay, which is the time required to collect measurements from member nodes and to process the estimation.
- **Relay selection phase:** After cluster formation phase, all information from non-CH members is forwarded to the CH and this CH, in its turn, needs to continue to forward to the BS. In order to do this, CH selects a relay node by broadcasting request relay messages to its neighbors, waits for acknowledgements from all candidates and selects the a relay one according to the relay node function (Eq. 4 and Eq. 5). This phase causes obviously a sub-delay to the total end-to-end latency of system and we call it T_{relay}.
- **Report phase:** After relay node selection phase, CH reports the target state to the BS. The delay of this process is denoted as T_{report}. It is also important to recall that two processes (relay node selection and report) can be repeated many times until CH reaches the BS. In other words, the sum of T_{relay} and T_{report} is multiplied several times based on the number of hops along the path towards BS.

Among these sub-delays, we realize that the initial delay can be considered as the physical element of sensor's hardware for switching from inactive to active state. More concretely, it depends mainly on the type of sensor used in system. The second delay element is target detection delay and as analyzed previously, it consists of hardware response delay, discrete sampling delay and other components. However, all these components also depend on node's type. Therefore, we focus on the calculation of the last three sub-delays: cluster formation, relay selection, and transmission. Those sub-delays reflect the performance of our tracking system.

The delay when using EMRP routing can be calculated as follows.

$$\begin{aligned} T_{e2e} \;=\; & T_{cluster} + T_{process} \\ & + n_1 * (T_{relay} + T_{report}) \\ & + n_2 * (T_{relay} + T_{report}) \end{aligned} \tag{9}$$

where $N = n_1 + n_2$ is number of hops for reaching BS, n_1 is total relay node on the route to BS, n_2 is total node find relay node on the route to BS.

V. PERFOMANCE EVALUATION

We develop computer simulation to evaluate the performance of the Lateration method and compare to EKF method by using the same EMRP protocol. In the simulation, we use the same network model, measurement model, and radio model as mentioned in [7], [18]. We assume that *950* sensor nodes are uniformly and randomly deployed within a square field of *640 × 540* square meters. The base station is located at *(320,540)*. Each sensor node is provided an energy level of *1J* at the start. We assume that one target are moving in the sensing field with average speed of *10 m/s*. Measurement noise is *5-10%* of sense range. The energy consumption of sensor nodes and tracking accuracy is recorded and compared as a function of varying the parameters.

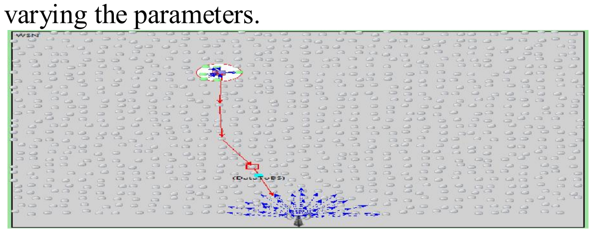

Figure 3. A simulation screenshot in OMNet++

Table 2. Simulation parameters

Parameters	Values
Initial Energy	1J
Data Packet Size	128 bytes
Broadcast Packet Size	30 bytes
Network Area	640*540
Transmitting Range	100m
Sensing Range	25m
Number of nodes	950
E_{elec}	50nJ/bit
E_{fs}	10pJ/bit/m2
Switching level	5%

1. Target Trajectory

Following figures plot the true trajectory of the target and its trajectories received at the BS from our tracking system using Lateration and EKF methods. Fig.

4 shows that target trajectories obtained from both Lateration and EKF methods are similar compared to true trajectory. We also evaluate the accuracy of tracked trajectories of the moving target when we assign different values for the sampling interval parameter: *1, 1/3,* and *2/3* second. The results are shown in Fig. 5 and Fig. 6. As described in these figures, when the sampling interval has the smallest value, the tracking system achieves the best accuracy. Depending on the quality of service requirement of application and network resources, users can vary these parameters to acquire better performance in the aspect of network lifetime and tracking accuracy.

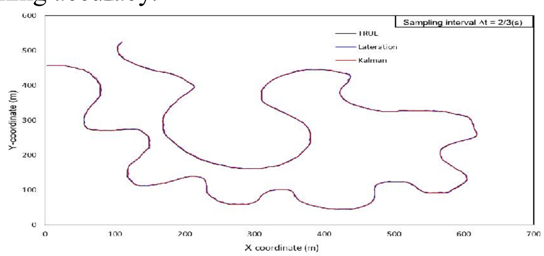

Figure 4. Full target trajectory with sampling interval 2/3s

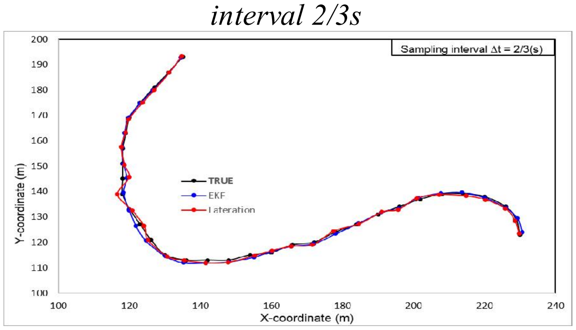

Figure 5. A part of target trajectory with sampling interval 2/3s

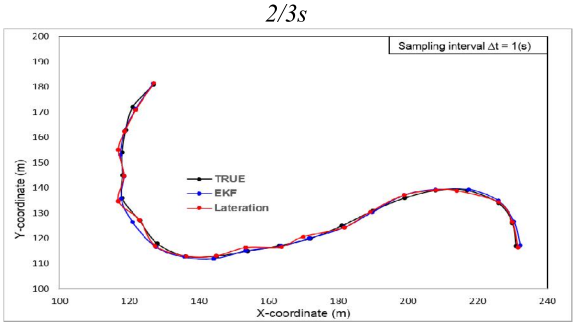

Figure 6. Target trajectory with sampling interval 1s

For an accurate evaluation, we evaluate also the tracking accuracy between true trajectory and the trajectories of Lateration and EKF method. This metric is presented in Fig. 7.

From this figure, we can easily find that the EKF prediction method has better quality than the Lateration. In other words, the trajectory plotted by EKF is more identical to true trajectory than Lateration. However, Lateration method can still achieve a reasonable tracking accuracy while consuming less energy than EKF does. We discuss this fact in the following subsection.

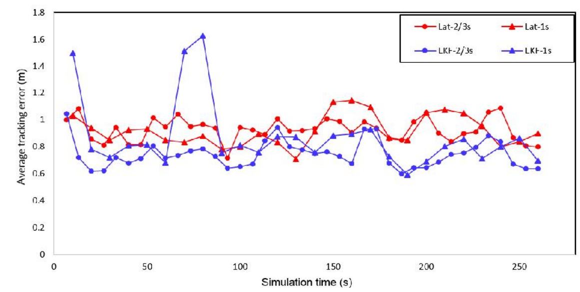

Figure 7. Comparison of average tracking error between Lateration and EKF methods

2. Energy-Efficiency

In this subsection, we evaluate the variation of total residual energy of our WSN in both cases: using Lateration and EKF filter. Figure 8 shows a comparison of the total residual energy of sensor nodes in varying of sampling interval (*1*, *1/3* and *2/3* second). Clearly, longer sampling interval results in higher residual energy level of sensor nodes while tracking performance becomes lower. On the other hand, with the same sampling interval, the Lateration method helps sensors to consume less energy than the EKF methods. This important feature can be explained as follows:

- EKF is not only an estimation but also a prediction method. After estimating and predicting the location of target by using EKF, it is necessary to broadcast the state estimation and the updated covariance matrix of the state $(P(k|k), \hat{x}(k|k))$ to one-hop neighbors [16]. This information will be used by next CH in order to predict and estimate the target's information.
- Lateration needs only the sensed information of sensors for estimating the location of the target at the present time and transmit this location information towards BS. Unlike EKF, it is not necessary to broadcast any further information to next CH. That is

why the tracking system using Lateration consumes less energy than the EKF method.

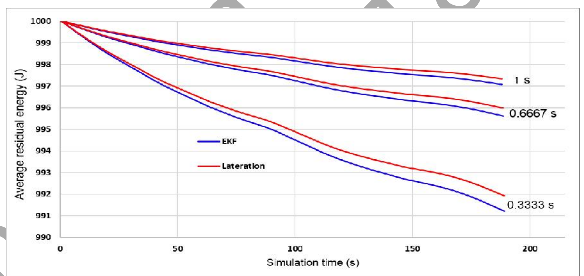

Figure 8. Total residual energy of Lateration and EKF methods as a function of simulation time

3.End-to-end delay

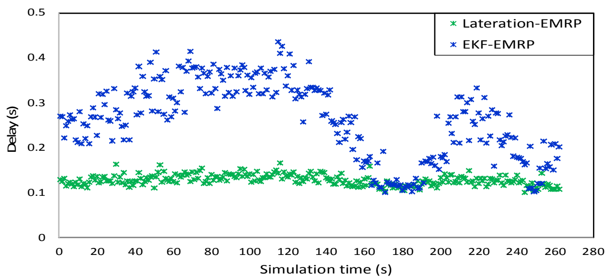

Figure 9. Comparison of end-to-end delay

In order to assure real-time property of our system, the end-to-end delay needs to be smaller than sampling interval. In this section, we evaluate this important metric when sampling interval is *1s*, target speed is *10m/s* and sensing range is *25m*. The metrics of MAC layer is defined in previous section. Working period is equal to sampling interval and duty cycle $\beta = 0.4$.

The end-to-end delay of the system is plotted in the Fig. 9. We compare the end-to-end delay of the tracking system with Lateration + EMRP and EKF + EMRP underlying the same proposed MAC protocol. From this figure, we realize that end-to-end delay of the system in all cases is always smaller than *0.5s* or the real-time property of the system is assured. Depending on the tracking accuracy, we can both select sampling interval bigger than *0.5s*. More concretely, in case of EMRP using Lateration, end-to-end delay is only *0.45s* and this system is very appropriate to the application that needs high tracking accuracy.

4.Network Lifetime

Clearly, where many nodes are dead or density of nodes decreases significantly, we will get low network connectivity. One of main goals in a target tracking system is to avoid this problem. In other words, the main design feature of our system is to balance the node's energy consumption in order to avoid hot spot, which causes quick deaths of the nodes due to their overload.

In Fig. 10, we plot the residual energy of nodes in the network. Compared to another system that implement also EMRP protocol associated with EKF method for localization mission, EMRP and Lateration method achieves better energy level and better load distribution. This is an important feature because it helps to extend the network lifetime of system. Network lifetime of the system is also examined and evaluated in Fig. 11. From this figure, it is clear that EMRP and Lateration achieves better network lifetime than EMRP and EKF.

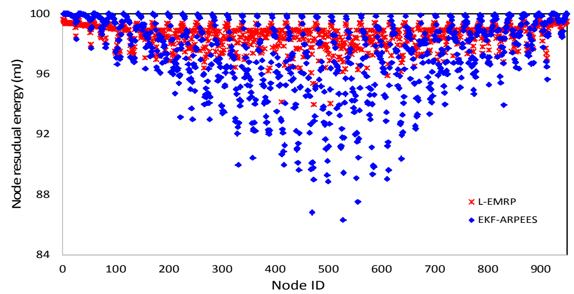

Figure 10. Comparison of load balance

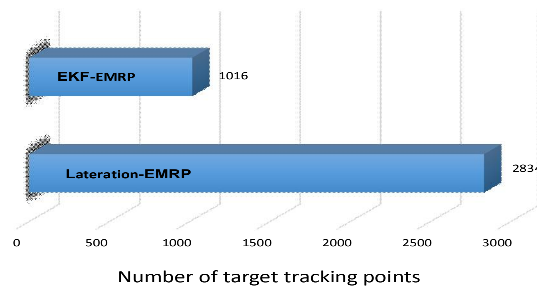

Figure 11. Target loss ratio with the variation of sensing range

VI. CONCLUSION

In this paper, we analyze the components of a tracking system and also the requirements that a real time system will affect the design of its wireless medium access. We propose to utilize the unbeaconed and unslotted MAC protocol of 802.15.4 for our system. Simulation shows that end-to-end delay caused can satisfy the requirements of real time property while still assuring energy efficiency. In the future work, we will evaluate the proposed system with multi-target tracking in real-time.

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REFERENCES

[1] J. Chen, X. Cao, P. Cheng, Y. Xiao, Y. Sun, Distributed collaborative control for industrial automation with wireless sensor and actuator networks, Industrial Electronics, IEEE Trans. 57 (12) (2010) 4219–4230.

[2] B.-S. Choi, J.-W. Lee, J.-J. Lee, K. T. Park, A hierarchical algorithm for indoor mobile robot localization using rfid sensor fusion, Industrial Electronics, IEEE Trans. 58 (6) (2011) 2226–2235.

[3] K.-F. Ssu, C.-H. Ou, H. Jiau, Localization with mobile anchor points in wireless sensor networks, Vehicular Technol., IEEE Trans. 54 (3) (2005) 1187–1197.

[4] T. Naumowicz, R. Freeman, H. Kirk, B. Dean, M. Calsyn, A. Liers, A. Braendle, T. Guilford, J. Schiller, Wireless sensor network for habitat monitoring on skomer island, in: Local Computer Networks (LCN), 2010 IEEE 35th Conf., 2010, pp. 882–889.

[5] T. Alhmiedat, A. Taleb, M. Bsoul, A study on threats detection and tracking systems for military applications using wsns, Int'l Journal of Computer Applications 40 (15) (2012) 12–18.

[6] X. Chen, N. C. Rowe, J. Wu, K. Xiong, Improving the localization accuracy of targets by using their spatial-temporal relationships in wireless sensor networks, J. Parallel Distrib. Comput. 72 (8) (2012) 1008–1018.

[7] Vinh Tran-Quang, Hung Nguyen-Khanh, Thu Ngo-Quynh, "Target Tracking System using Lateration Estimation method in Wireless Sensor Networks", accepted paper at the fifth International Conference on Ubiquitous and Future Networks (ICUFN 2013), July 2-5, Danang, Vietnam.

[8] C.-T. Lee, F. Yeong-Sung Lin and Y.-F. Wen, "An Efficient Object Tracking Algorithm in Wireless Sensor Networks," in JCIS-2006 Proceedings Advances in Intelligent Systems Research, October 2006.

[9] H.-W. Tsai, C.-P. Chu and T.-S. Chen, "Mobile Object Tracking In Wireless Sensor Networks," Computer Communications 30, 2007, pp. 1811– 1825.

[10] H.T. Kung and D. Vlah, "Efficient Location Tracking Using Sensor Networks," in Proceedings of the IEEE Wireless Communications and Networking Conference (WCNC 2003), March 2003, New Orleans, Louisiana, USA.

[11] C.-Y. Lin, W.-C. Peng, and Y.-C. Tseng, "Efficient In-Network Moving Object Tracking in Wireless Sensor Networks," Department of Computer Science and Information Engineering - National Chiao Tung University, 2004.

[12] E. Olule, G. Wang, M. Guo and M. Dong, "RARE: An Energy Efficient Target Tracking Protocol for Wireless Sensor Networks," 2007 International Conference on Parallel Processing Workshops (ICPPW 2007), 2007.

[13] M. Walchli, P. Skoczylas, M. Meer and T. Braun, "Distributed Event Localization and Tracking with Wireless Sensors," in Proceedings of the 5th international Conference on Wired/Wireless internet Communications, May 23 - 25, 2007.

[14] D. Fox, J. Hightower, L. Liao, and D. Schulz, "Bayesian filtering for location estimation," IEEE Pervasive Comput., vol. 2, pp. 24–33, July 2003.

[15] Y. Bar-Shalom, X. Li, T. Kirubarajan, Estimation with applications totracking and navigation, Wiley, New York, 2001.

[16] S. Julier and J. Uhlmann, "A new extension of the kalman filter to nonlinear systems," in Int'l Symp. Aerospace/Defense Sensing, Simul. and Controls, 1997, pp. 182–193.

[17] L.N. Al-Karaki and A.E. Kamal, "Routing techniques in wireless sensor networks: a survey," IEEE Wireless Commun. Mag., vol.11, no.6, pp.6-28, Dec. 2004.

[18] T. T. Vinh, T. N. Quynh, M. B. T. Quynh, Emrp: Energy-aware mesh routing protocol for wireless sensor networks, in: Advanced Technologies for Commun. (ATC), 2012 Int'l Conf., 2012, pp. 78–82.

[19] I. Std., Ieee standard for information technology part 15.4: Wireless medium access control (mac) and physical layer (phy) specifications for low-rate wireless personal area networks (wpans), 802.15.4-2006.

[20] B. Latr, P. D. Mil, I. Moerman, B. Dhoedt, P. Demeester, N. V. Dierdonck, Throughput and delay analysis of unslotted ieee 802.15.4., JNW 1 (1) (2006) 20–28.

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