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Object Tracking Sensor Networks in Smart Cities: Taxonomy, Architecture, Applications, Research Challenges and Future Directions

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ABSTRACT

The development of pervasive communication devices and the emergence of the Internet of Things (IoT) have acted as an essential part in the feasibility of smart city initiatives. Wireless sensor network (WSN) as a key enabling technology in IoT offers the potential for cities to get smatter. WSNs gained tremendous attention during the recent years because of their rising number of applications that enables remote monitoring and tracking in smart cities. One of the most exciting applications of WSNs in smart cities is detection, monitoring, and tracking which is referred to as object tracking sensor networks (OTSN). The adaptation of OTSN into urban cities brought new exciting challenges for reaching the goal of future smart cities. Such challenges focus primarily on problems related to active monitoring and tracking in smart cities. In this paper, we present the essential characteristics of OTSN, monitoring and tracking application used with the content of smart city. Moreover, we discussed the taxonomy of OTSN along with analysis and comparison. Furthermore, research challenges are investigated concerning energy reservation, object detection, object speed, accuracy in tracking, sensor node collaboration, data aggregation and object recovery position estimation. This review can serve as a benchmark for researchers for future development of smart cities in the context of OTSN. Lastly, we provide future research direction.

Keywords: Object Tracking Sensor Network; Smart City; Monitoring; Object Recovery; Energy

1 Introduction

In the recent decade, the proliferation of sophisticated communication devices [1], as well as the substantial increase in connecting devices such as sensor and actuators have made it possible to visualize the living in a smart environment. Numerous applications of the smart environment have been presented in the recent years, including smart logistics, transportation, agriculture, Hospital [2], security and emergency [3]. Because of the rapid urbanization and growth of the population density in the urban region, currently, urban monitoring and tracking depends not just on the physical structure but also on the volume of data shared between people, devices and social infrastructure [4]. The transformation of the aforementioned smart city applications is due to the advent of IoT in which objects are self-con Fig.1 and connected to each other through a network technology.

The advent of the smart city leads to monitoring or tracking different sectors in the city by integrating the areas with communication devices [5]. The communication devices produce volumes of data regarding the object they monitored. Indeed, the applications of smart cities can be categorized as monitoring only or monitoring and tracking. In monitoring objects, sometimes the object is stationary and has no movement. Such kind of objects is monitored only. While moving object in a smart city is observed and tracked by sensor and actuator. Fig. 1, illustrates the tracking and monitoring application for the smart city in which various smart city applications used sensor node and another device to communicate and exchange information among themselves regarding the condition of the object. Some of the data is processed in cloud-computing infrastructure, while the base station handles others.

The concept of smart cities played an essential role in improving the quality of life, transforming different areas of human life and changing areas such as logistics, environment, security, and hospital. For example, the data of environmental monitoring are significantly increased due to urbanization. Analyzing the data to obtain valuable information from the massive amount of environmental data can help to inform people about any possible hazardous situation (e.g., chemical or gas pollution, earthquake and flood information, and soon on) [6]. Law enforcement agencies have started embracing smart city ideas to improve citizens' living standard and, to implement tracking and monitoring application [7]. Monitoring and tracking of city activities can help the government to take preventive measures before happening something drastically to know the characteristics of the smart city. These features include but not limited to improvement of living standard, law enforcement, and resources monitoring. To utilize smart city, WSN is an enabling technology that can reduce the cost of maintenance and resources usage.

WSN is a network that comprised of hundreds of thousand nodes that are battery powered, have limited computational resources and connected wirelessly. Such nodes are built with a little cost, and they can be used for multi purposes. WSN is deployed in a region usually called monitor region for monitoring different targets [8], [9], [10], [11]. WSN is capable of sensing, gathering, and processing environmental information and communicates the information with the neighboring node using Hop-by-Hop communication.

Monitoring can be performed for both indoor and outdoor environments. Monitoring could be event-driven, after that detecting an event; the network will react to the event either by informing the user or set up an alarm. Moreover, after event detection, the network will track the movement trajectories of the object(s) by activating only the nodes that are on the path of tracking an object and deactivating those that are not. Because of the nature of object tracking, sensor nodes report information of the object movement, which has some issues such as energy consumption. To minimize the energy consumption, when there is no event, the nodes are kept in the idle or sleeping mode to reduce the amount of energy overhead [12], [13].

Although many researchers [12], [13] have conducted studies in the recent years on OTSN, our work differs from the previous works regarding comprehensiveness, characteristic of OTSN. The article investigates the recent state-of-the-art work on OTSN from a different view, particularly regarding a smart city. Furthermore, the study explores the most recent advances and disclose open challenges regarding OTSN in smart cities.

The contribution of the study are as follows:

- OTSN essential characteristics with the life cycle.
- A taxonomy is derived by categorizing the recent literature.
- We outline and discuss research challenges that need further consideration.
- Finally, we presented future research directions.

The rest of this paper is structured as follows. Section 2 presents the definition and essential characteristics of monitoring and tracking of an object in a smart city. Section 3 shows monitoring and tracking applications; Section 4 presents the classification of OTSN according to the target tracking algorithms. The presentation of Research challenges in OTSN in Section 5. Section 6 discusses Open research issues and future direction in OTSN. In Section 7, we analyze and compare the algorithms in a graphical presentation. Finally, Section 8 concludes this study.

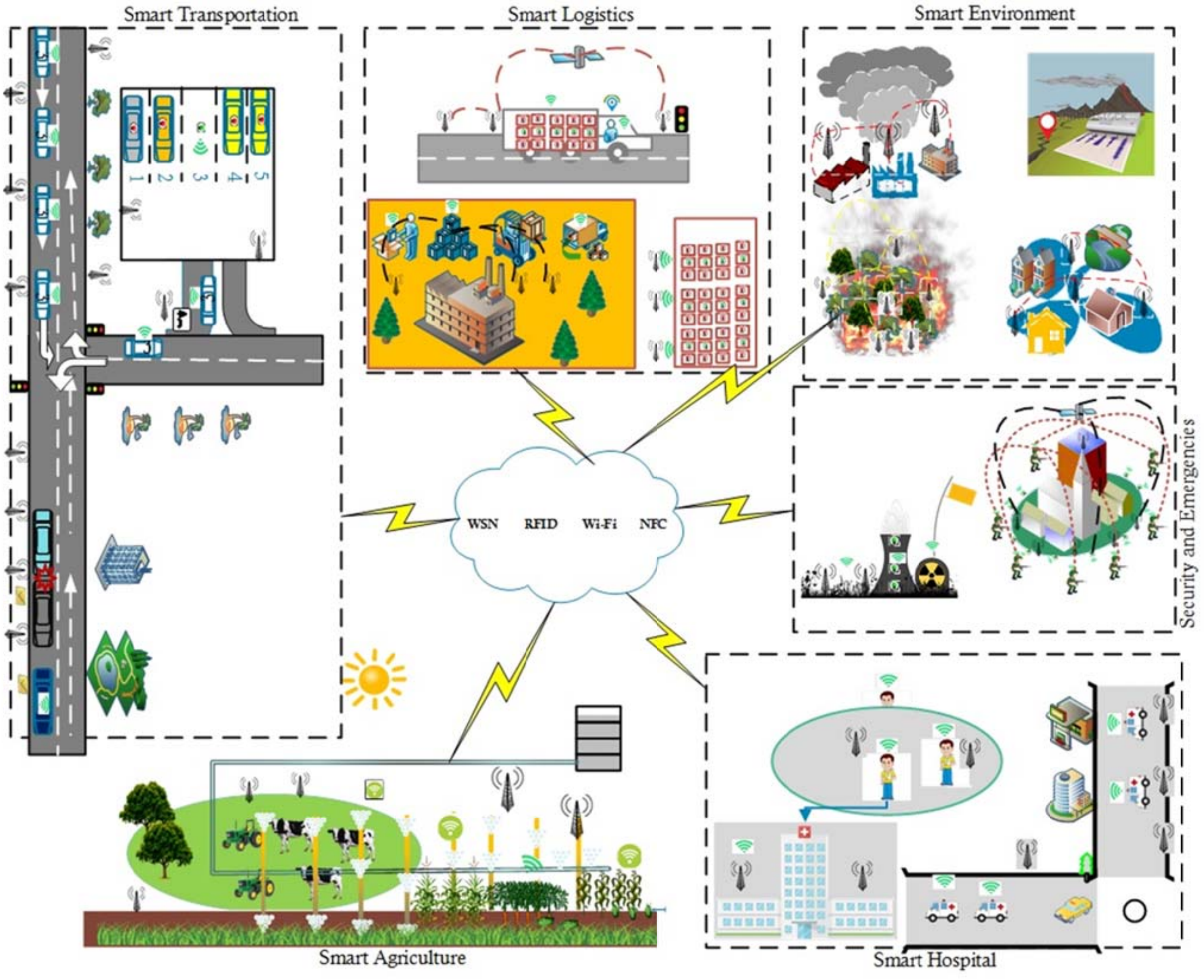

Fig. 1. Smart city monitoring and tracking applications

2 Essential characteristics of monitoring and tracking objects in smart city

Object tracking has received tremendous attention by researchers in the recent years. Object tracking is not new; however, it is still on rising in WSNs, and several researchers worked on object tracking in contemporary literature. For instance, in [14] authors referred to object tracking as a way of tracking objects by predicting the location of the target position and to follow or capture the target by using active nodes to sense the area and find intruders. There are many definitions for target tracking that used by researchers. For instance, in [15], authors have stated, “Tracking could be defined as establishing

coherent relations of targets between successive events that indicate the movement of the target." Meanwhile, object tracking deals with several requirements as shown in Fig. 2, including node deployment, target detection, node cooperation, position computation, prediction, energy management and object recovery. We investigate these requirements because of the consideration in most of the object tracking applications (Table 1). The following definition is proposed based on the previous definitions and our observation and analysis:
Object tracking in WSN is a process of detecting an intruder in a monitored location, and track the intruder with a minimal number of sensor node possible in the network.

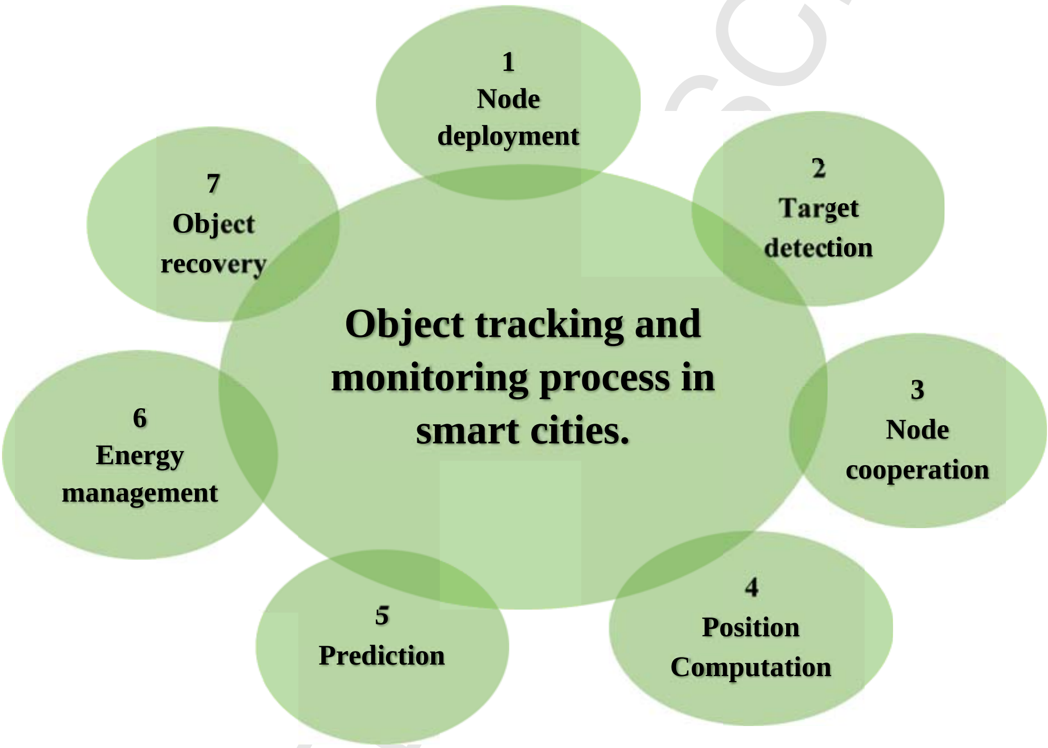

Fig. 2. Object tracking and monitoring requirements in smart cities

3 Monitoring and tracking application in smart city

Using monitoring and tracking in smart city applications enables an efficient way of processing and analyzing information that can improve the services provided in the smart city. Also, the gathered information in monitoring and tracking helps in decision making shortly. To get efficient monitoring and tracking in smart cities, it needs the right communication devices and methods for effective and efficient data processing. These practices encourage collaboration between communication devices. Table 2 provides a summary of the smart city applications.

3.1 Smart transportation

The amount of information gathered for the traffic data center can help to improve the transportation system. It can mitigate colossal traffic congestion due to accident or in rush hours, by merely providing alternative routes to the drivers [23]. Moreover, the gathered information would be used to regulate the speed limit to reduce the number of accidents. Sensor and actuators can make the road intelligent, provide many benefits, such as increase safety of people, and reduce traffic congestion among many others.

Table 1. Object monitoring and tracking requirements in smart city

Index	Process	Descriptions
1	**Node deployment**	Refers to the process where the sensor nodes are deployed in the region of interest, the deployment can be in the form of deterministic or randomized. In deterministic the node knows their location details their coordinates and, the base station also knows its location, while in randomized. None of the node knows the position they will stay, usually, is used in a position that is impossible for a human being to access, the node will be deployed at random [16].
2	**Target detection**	Refers to the discovery of the target when the target has entered a monitor region, this target can either be a discrete or continuous target [17]. For example, animals, military, border traces pass.
3	**Node cooperation**	After the detection, the next step that follows is node cooperation [18]. A single node cannot track object alone, so by interaction, multiple nodes can participate in the tracking process and reduced the total energy consumed by the network.
4	**Position computation**	At this stage, the target is mobile so the position will be changing because of the mobility [19]. The neighboring nodes compute its new location and send the new location to the calculated area for monitoring the object.
5	**Prediction**	After the computation of the position, it will predict the possible location that the node will trail and then turn on the node that is in the expected path for monitoring [20].
6	**Energy management**	Because tracking consumes much energy, [21] only nodes that are closer and their residual power is above the minimum threshold will participate in the tracking of the target.
7	**Object recovery**	Finally, target tends to lose in the process of tracking due to node failure so that the target will be recovered based [22] on the last known location, speed, and direction.

3.2 Smart logistics

In the past decades, goods processed and used traditionally; however, with the advent of smart communication devices, products are now monitored by sensor devices in the warehouse. Each item has a sensor device that monitors the condition of the good. Furthermore, products are monitor while they are transferred from the storage to retailers. For instance, in [24] the authors used sensor and actuators to prevent goods decay due to the variation of temperature. They could reduce the enormous amount of lost and increase customer’s satisfaction and company‘s reputation.

3.3 Smart Environment

Pervasive sensing technologies enable the use of monitoring and tracking. Ubiquitous devices might be deployed in a sensitive position (e.g., Flood monitoring, contamination monitoring, firefighting, earthquake) to supply the information about the location to take necessary measure before the occurrence of a disaster [25]. Smart environments help in mitigating the risk of citizen affected by examples above and reducing the amount of damage.

3.4 Smart Hospital

Integrating pervasive sensing technology into healthcare system will produce an enormous amount of data [26] regathering patients, medicine or medical equipment. Healthcare specialist to analyze data generated by the communication devices uses proper analytics tools. Proper analysis can serve to predict any epidemic and disease and improve the patient's quality of liveliness as good as avoiding sudden preventable death. Also, smart healthcare can enable doctors to monitor their patients remotely, and they can detect any sign of serious illness, which can save many lives.

3.5 Smart Agriculture

With the rapid amount of data produced by pervasive devices, management of agricultural plant production becomes feasible. The proposed intelligent irrigation system in [27] for Smart agriculture can collect data regarding temperature and use the data obtained from sensor devices by performing analysis on a various set of conditions that might help in the growing plants. Hence, the right quantity of water that is required by the plants will be supply, and by avoiding excessive water that might spoil the plant. Smart agriculture enhances a various aspect of agriculture such as, water quality monitoring, automatic improvement of water quality, proper fertilization that saves fertilizer, monitoring soil constituent, soil humidity, light, wind, and air.

3.6 Smart Security and Emergencies

Boarder's security is one of the leading application of smart cities. In [28] security agencies used the information produced by pervasive deceives to detect intrusion detection for border surveillance and track the target. Moreover, hazardous gases, the radiation level is monitored to ensure citizen safety, by taking preventive measure.

Table 2. Summary of smart city applications.

Application	Usage	Strengths	Weaknesses
Smart Transportation	Parking, intelligent traffic management, smart road.	Automatic notification system.	-A network failure can cause catastrophic accidents.
Smart Logistics	Supply chain, excellent location, fleet tracking, storage incompatibility detection	Increase health safety	-Failure of monitoring will cause massive loss.
Smart environment	Flood monitoring, firefighting, earthquake.	Increase the safety of peoples' life.	-Failure of the network can cause tremendous damage. -Costly.
Smart hospital	Patient surveillance, medical fridges.	Early detection of disease.	Lack of accuracy
Smart Agriculture	Soil moisture, animal tracking, paste control.	Increased agricultural productivity and income.	Gathering and analyzing information seems difficult.
Smart Security and Emergencies	Radiation level monitoring, perimeter access control, hazardous gases.	Improved security	Management is difficult. Costly.

4 Object tracking sensor networks

OTSN can be defined as the ability of the sensor to locate the location of the mobile object(s) and trace the paths in which the object moved. OTSN has two most critical stages: 1) monitoring: sensor node is required to monitor their sensing region for an intruder; 2) tracking: the sensor node that detects an intruder has to track the object as long as it resides in its vicinity. These two stages are interchangeable during the entire process of object tracking.

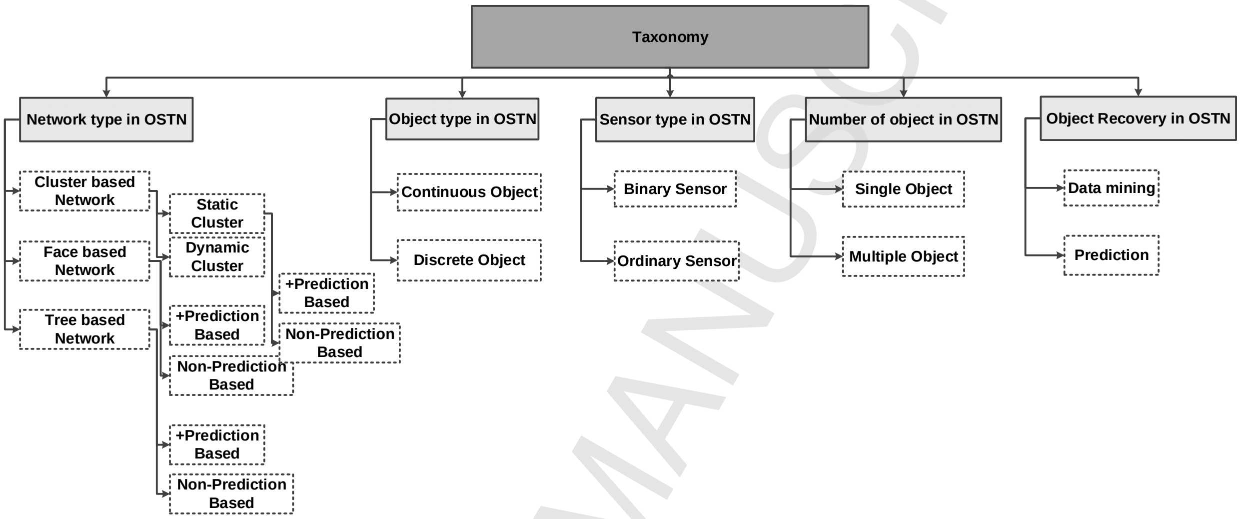

Fig. 3. OTSN taxonomy

In this section, we discussed the classifications that we have used in grouping the most recent works of object tracking. As shown in Fig. 3, there are five classifications: Network type in OTSN, Object type in OTSN, Sensor type in OTSN, number of the object(s) and Object recovery type in OTSN.

4.1 Network types in OTSN

In [29], the authors have categorized the network architecture into four categories: naïve based, cluster-based, tree-based, and hybrid-based protocols. Some of these types have incorporated prediction mechanism to reduce the energy consumption of the network and the probability of losing the mobile object(s) location. Furthermore, in [11] the authors have categorized network-centric object tracking protocols in the WSN structure into cluster-based, tree-based, and leader-based structures. Each of the protocols can be in the form of prediction based or non-prediction based. We have categorized the network architecture into Cluster-based networks, Face-based networks [30], and tree-based network [31].

4.1.1 Cluster-based network

Clustering in WSN is a process of grouping sensor nodes into clusters, after the deployment of the nodes to reduce the number of active node and energy consumption in the network. In each group, there is a cluster head (CH), and the CH would be the one in charge of communicating with other clusters and member nodes [32], [33], [34]. When a member node detects an object in its vicinity, it will inform its CH, which aggregate and report all the data received by the base station for further action. In a situation, whereby the object moved out of the vicinity of the current cluster, the neighboring cluster will be

informed about the object, and then the new CH will send a message to its members to wake them up and search for the missing object.
In object tracking applications, some of the nodes can be active while other nodes would be in a passive mode to increase the network lifetime. Furthermore, cluster members might have an election between them based on some parameters (i.e., energy level). The cluster-based network can be further divided into two classes, static or dynamic clustering.

4.1.1.1 Static Clustering

In static clustering as shown in Fig. 4, after the formation of the network there will be no changes in the networks, i.e., the CH will remain the head for the entire network lifetime, and members will be going to stay the members as well.

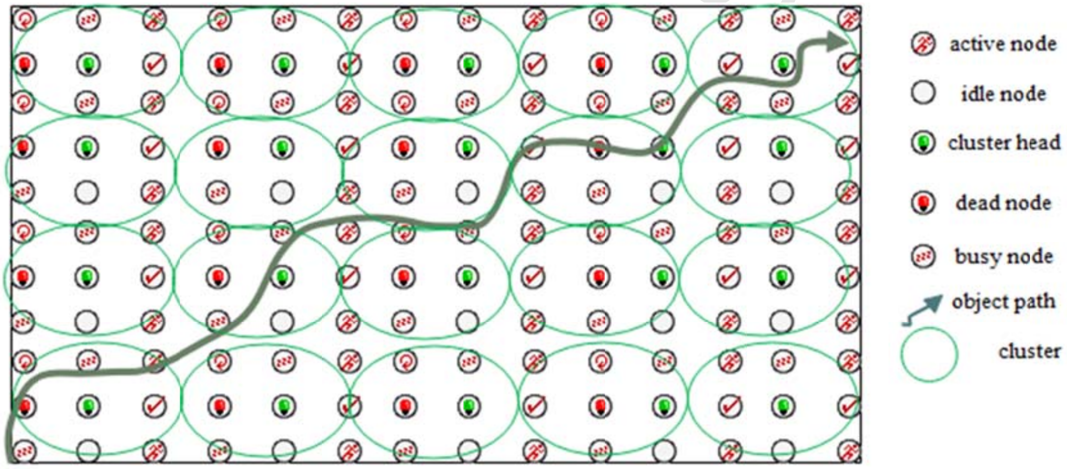

Fig. 4. Static clustering scenario

Once the CH exhausted its energy, the whole cluster will be of no use because they cannot elect another cluster head [35]. Static clustering can further be categorized into two categories: prediction and non-prediction based. In the prediction based group, the cluster head predicts the next location of the mobile object, then the node in the expected position would be turned on to monitor the mobile object and report the object properties to the base station [36]. While in the non-perdition based category, the object is monitored based on its features, (e.g., location, speed, size).

4.1.1.2 Dynamic

In dynamic clustering as shown in Fig. 5, clusters are formed only when there is an object detected by sensor nodes. Thus, the CH checks the sensor nodes that are in its coverage and inform them to join its cluster to track the object. The issue with dynamic clustering is that some nodes can be selfish or non-cooperative.

4.1.2 A face-based network

In a face-based network, network formation has two stages 1) Inner-face identification and 2) Outer-face identification. In inner-face ID, a sensor node will broadcast an in-face message to its neighbors. The neighboring node will calculate its angle of direction and reply to the source. Then, the source will choose the node with a maximum edge to be in its Inner-face. On the other hand, While Outer-face identification is similar to Inner-face, but it selects the node with the least edge to be in its outer face. Face based network is built using Gabriel graph (GG) and relative neighborhood graph (RNG) [30].

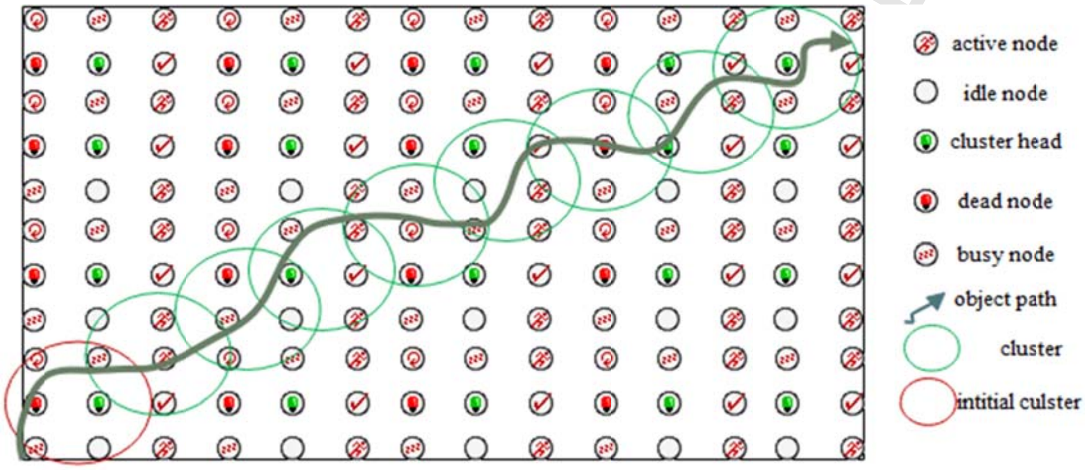

Fig. 5. Dynamic clustering scenario

Furthermore, face network can be combined with prediction mechanism. In [30] authors have proposed a prediction based object recovery method in which only the node that is in the predicted location is requested to wake up and search for the missing object. It can also work without the prediction mechanism where the sensor node will be storing the movement information of the object [37]. In Table 3, present a comparison between the most recent proposed methods in the literature concerning their strengths and weakness.

4.1.3 Tree-based network

In [38], [39], [40], researchers have adopted the tree-based method to reduce the energy consumption in a tree-based network. In these works, a sensor node can either be a root, parent or child node. The child node detects the target and then inform its parent node. Then, the parent nodes inform the root. The root node is responsible for notifying the base station. Necessary messages are exchanged between sensor nodes to form the network; so that, each node can determine its parent or child nodes. However, due to the distance between the child nodes and the root node, the target can move out of the child nodes' vicinity. In this case, another child should detect the object and make another path. This network type is not efficient in term of energy consumption.

Table 3. Comparison of Object tracking sensor network, network types

Reference	Network structure	Description	Strengths	Weaknesses
(Zarifneshat, Khadivi, & Saidi, 2015)	Cluster-based Network	Sensor nodes are group into clusters, where each cluster has a cluster head and members.	CH gather and aggregate the information to reduce redundant information	CH energy depleted quickly.
(Hsu et al., 2012)	Face-Based Network	Sensor nodes are group into Face. Each face has some nodes, and each node knows next node and its neighbors face.	Tracking object by a node of the same face. The accuracy of tracking can be increased.	A node that is close to BS is heavily used. If node energy is depleted, the tracking accuracy is going to be reduced.
(W. S. Zhang & Cao, 2004)	Tree-Based Network	Sensor nodes are group into a hierarchical tree or in a graph form. Where the vertices represent a node and edge the link that connects nodes.	A total number of inquiries for information is reduced based on the branch structures.	Nodes that are close to the root node are heavily loaded.

4.2 Object type in OTSN

The tracking object can be in different shape, size and weight for its properties. The object can be 1) eternal (forest fires, polluted air, bio-chemical material) or 2) discrete object. (Car, animal).

i. *Continuous object tracking*: in the literature, some works focus on continuous mobile objects [41]. Because of the nature of the objects, they can expand and increase in size to occupy a vast area or even split into fractions due to monitoring a continuous object is energy consuming. The authors in [41] have provided a solution for energy consumption by using prediction, selective wake-up and structured clustering schemes. The proposed work reduced the energy consumption and increased the accuracy. In [42], several similar works are reviewed. In [43], the authors have proposed a continuous object-tracking algorithm (COTA) in which the distribution of homogenous sensor nodes are even. This work does not use clustering; thereby, it increases the life cycle of WSNs without losing sight of the targets. However, the whole network will run down soon, because the energy level of the nodes is not considered. In [44], [45], [46], the authors have proposed a scheme that monitors and tracks a continuous object. However, boundaries in continuous target tracking are dynamic; changes are randomly in the boundary. The proposed protocol is not adaptable to all situations.
ii. *Discrete object tracking*: Researchers have developed many algorithms and protocols that used discrete object [47], [30], [48], [49], [50], [51], [52], [53], [54], [37], [15], [55], [56] . However, there is still no standard protocol or algorithms than can be applied to all types of discrete object application.

4.3 Sensor type in OTSN

Sensors can be classified as binary or ordinary sensors:

i. *Binary sensors*: Binary sensors (BIS) [57] are a type of sensors that has only two states of operation, either 0 or 1. 0 can be used to represent detection of an object, and one is indicating the absence of an object. Furthermore, the reading (0 or 1) is used when an object is moving closer to the sensor node or when it is moving out of the vicinity. Comparing to another type of sensors, BIS are low-cost, and their energy consumption is considerable because of the binary state operation.

ii. *Ordinary sensors*. Ordinary sensor (OS) [58] unlike BIS, OS have many operational stages, e.g., in target tracking, they use the values of the object (mobility type, direction) for the prediction of it next possible location and each sensor node can calculate it.

4.4 Number of objects in OTSN

OTSN might deal with single or multiple objects as follows:

i. *Single object*: The methods proposed in [59], [33], [30], [60], [36], [61], [15], [62] have the ability to track a single object. These works are energy efficient since frequent tracking of a single object does not require high computation because of the low traffic generated in the search for the object.

ii. *Multiple objects*: In general, tracking multiple objects is a challenging and consuming high-energy. Especially when the number of objects is increasing, it will become more challenging due to differences in speed, direction. When there are many objects, it would be difficult to know which observation belongs to which object. In [63], [64], [65], [66], [67], [57], [68], [69], [70], [71], [72], [73], [74] authors have proposed different solutions for solving the problem with multiple object tracking approaches. In [63], the authors proposed a rule-based algorithm for multiple objects target tracking by using acoustic sensor nodes. The proposed work employs a special fusion center that collects the detection information (detecting sound power and source ID) and aggregates such information in clusters. However, sensor node must send its detection information to the fusion center directly without communicating to its neighboring nodes. Thus, transmission from the sensor node to fusion center will consume high energy. In [75], authors have proposed two sub-optimal decision fusion algorithms named range-limited marginalization (RLM) and Parallelized range limit marginalization (PRLM) to reduce the computation and complexity of multiple objects target tracking [76], [77], [78]. In this work, multiple target location is estimated using hybrid QVF and sequential Monte Carlo-based approach to data association (SMCDA). The proposed approach has creased the prediction estimate of the target location; however, it does not consider the energy level of sensor nodes. In Table 4, present a comprehensive summary of the OTSN related work. The table also highlights the contributions of the works.

4.5 Object recovery in OTSN

The monitored or tracked object can be lost in the process of tacking. The possible reasons could be node failure, coverage holes, or non-collaborative nodes. Researchers have proposed some object recovery schemes to address this issue. In [36], mobility model uses to recover the object by using constant acceleration and direction to predict the possible location of the missing object. In this work, a wake-up message is sent to those nodes that are close to the predicted location. In [30], the authors have proposed an object recovery algorithm that considers the last known location of the object. The, it calculates the possible next location of the object by considering the maximum moving speed of the object and wakes up all nodes that are in the same face which their distance to the object lost location is less than the total long distance.

Table 4. Object tracking sensor network summary of classification scheme

Network type	Reference & method	(+) Prediction	Object Type	Number of objects	Object Recovery	Energy efficient
Cluster-based Networks (+prediction)	[36]	Kalman Pilfer	Discrete	Single	No	Yes: it reduced the number sensor node that participates in the tracking.
	[85]	No	Discrete	Single	No	Yes: it uses hierarchical two-stage fusion structure, it minimized the number of fusion in the entire network.
	OCOT [86]	No	Continuous	Single	No	Yes: By using the one-to-many connection between the sink and sources detecting a continuous object.
	[45]	No	Continuous	--------	No	Yes: It saves sensor node energy; sink node can use previous information.
	DCMS [87]	No	Discrete	Single	No	Yes: By having, dynamic cluster members scheduling it solve the trade-off between tracking performance and energy consumption.
	[77]	No	Discrete	Multiple	No	Yes: It reduced the energy by using synchronization based sampling reduction
	[88]	No	Discrete	Single	No	Yes: They proposed a low-duty-cycle medium access control algorithms that reduced collision, idle-listening, and overhearing.
	[89]	No	Discrete	Single	No	Yes: By using two-level, the hierarchical network topology is adopted for energy efficient target tracking with information aggregation.
	[90]	No	Discrete	Single	No	Yes: By using a distributed target movement history recording algorithm it reduced target misses rate.
	PRATIQUE [8]	Kalman and Particle Filter	Discrete	Single	No	Yes: By using a hybrid scheme static and dynamic clustering. It reduces the cost of communication.
	[44]	No	Continuous	---------	No	Yes: by reducing the number of the neighboring nodes. The network lifetime is increased.
	CAICS [91]	No	Discrete	Single	No	Yes: It uses a dynamical selection of the best set of nodes for tracking missions.
	[92]	No	Discrete	Single	No	Yes: They proposed a target-tracking mechanism that minimizes the sensing redundancy and maximizes the number of sleeping nodes in the network.
	[63]	Kalman Filter Linear	Discrete	Multiple	No	Yes: Regarding network lifetime. A sensor node has no range or direct measurement capability.
	[78]	Quantized Variational filtering (QVF)	Discrete	Multiple	No	No. sensor energy level is not considering the whole network.
	AASA [93]	Auction mechanism	Discrete	Single	No	Yes: cluster head perform the computational for prediction.
	[46]	No	Continuous	---------	No	Yes: the entire network lifetime is increased because a small number of the sensor node is used in broader monitoring.
	[94]	Extended Kalman Filter	Discrete	Single	No	Yes: targets are tracked collaboratively by the cluster head and auxiliary head with a lightweight fault-tolerant mechanism
Face-Based networks (+prediction)	POOT [30]	Short-term prediction	discrete	Single	Yes	Yes: the only node that is in the same face will perform object tracking and monitoring.
	[59]	Kinematics-based prediction	Discrete	Single	No	Yes: the algorithm has reduced the number of a sensor node that will participate in detection.
	[95]	Linear Prediction method	Discrete	Single	No	Yes: It minimized the computational operation on sensor node; only sink node will predict the target position.
	FTTT [96]	No	Discrete	Single	No	No: Many nodes are included in object tracking, and energy level is not considered.
	PET [97]	Kalman Filter	Discrete	Single	Yes	Yes: It minimized the volume of the message and the time for neighbor discovery operations.
Tree-Based networks (+ prediction)	Distributed particle filter [98]	Particle Filter	Discrete	Single	Yes	Yes: sensor node energy saves because all the computations and aggregation are done at the root node. Which increases lifetime

	[99]	Particle Filtering	Discrete	Single	No	Yes: The proposed algorithm has lower communication overhead.
	[43]	No	Continuous	---------	No	Yes: Sensor nodes are homogeneous, and they are uniformly distributed.
	[100]	No	Discrete	Single	No	Yes: The proposed protocol improves the energy efficiency by 28.3% during data aggregation.
	DCTC [101]	Prediction-based scheme.	Discrete	Single	No	Yes: The proposed algorithm minimized the energy consumption under the certain ideal situation.
	[76]	No	Discrete	Multiple	No	No: Because Many sensor nodes are used in the monitoring and tracking the target.
	[75]	No	Discrete	Multiple	No	Yes: By reducing the complexity and computation of multiple, object tracking.

5 Research challenges in Object tracking sensor network

Although researchers have proposed many solutions in the area of OTSN. However, it continues to be in the forefront challenge of WSNs, many of the existing issues are not addressed by researchers to a satisfactory level. Furthermore, new challenges arise from different types of tracking applications. In the subsequent sections, some of the research challenges including energy constraint, object detection, object speed, tracking accuracy, sensor node collaboration, data aggregation and object recovery position estimation are discussed (Table 5).

5.1 Energy reservation

Energy reservation is the ability of the sensor node to minimize the energy consumption in a particular tracking or monitoring. Because, the sensor node is battery dependent, and the batteries have limited power, there should be a maintenance approach where sensor node can be put into sleep or idle, in order to save energy [79], [80], [81], [82], [83], [84].

A sensor node has four types of state: active or transmitting, receiving, sleep, idle or monitoring. When a sensor node is in active mode, it means that it has detected an object and is reporting the information to its cluster head or next node. When a node is in receiving mode, the node can only receive the reading, and it will not be able to do monitoring concurrently. In the sleep mode, the node is turned into sleep so the node can only receive a message, but it neither be able to monitor or transmit. Finally, in the idle modes, the node will be listing for detection of intruders.

In the literature, researchers have proposed many ways to limit the number of sensor nodes that will participate in either object tracking or recovery. In [59], [20], authors have proposed a prediction technique that will calculate precisely which node will be turned on to be part of the search or tracking of the object. However, energy remains the challenging factor that needs to be addressed to prolong network lifetime in object tracking.

5.2 Object detection

Object detection is the ability of a sensor node to detect an object that entered its vicinity based on the target classification. In [102], the authors have proposed an object detection technique for continuous object detection. The method used a hybrid method where static and dynamic clustering used for the detections. The method is suitable for different applications such as toxic gas and biochemical.

In object detection, different types of sensors including radio ultra-wideband, radio frequency identification, infrared, light, magnetic fluid, vibration, light, radar, image and visual are used in different ways [20], [86], [103].

5.3 Object speed

The speed of the object is a crucial aspect of the object detection. Objects might have dynamic speed level where they keep on changing from time to time, or they move with static speed level. In [104] authors have proposed work pertaining the variation in speed of the object; however, a standard protocol for object speed is not provided. Node position can be predicted with a predefined speed or last known object speed. Then, the node at the estimated location turns to active mode to search for the object, and since the speed is variable, the object may not be there. As a result, the energy of that node is not utilized since the prediction is not being accurate.

5.4 Accuracy in Tracking

Accuracy in object tracking is the ability to track the mobile object with a high probability of predicting the next location with minimal missing error rate. In [30], when a sensor node detects the object and the node is the closest to the object, then a wake-up message is sent to the nodes that are on the same face; so that, they participate in the tracking. When the object is going out of the face, the neighboring nodes inform the next face based on the object information (mobility, direction) to ensure the tracking object is monitor. However, there is room for improving the accuracy of the tacking.

5.5 Sensor nodes collaboration

Sensor nodes collaboration is the ability of a sensor node to communicate receive and forward packets. Researchers show that nodes tend to be selfish and greedy. When the nodes become uncooperative, the network will be broken. In [105], several methods where discussed that encourage nodes to collaborate by giving those rewards and incentives. Most of the proposed solutions are application dependent. Some tracking application cannot afford to lose the object because of the sensitivity of the application, (e.g., military, rescue operation). Efficient collaboration not only maintains the network connectivity and communication but also prevent transmission of redundant packets and increase network lifetime.

5.6 Data aggregation

Data aggregation is one of the most energy-efficient methods in WSNs. In the hierarchical structure, data sensed by a node is sent to a CH node or a leader node, and then all received data are aggregated and compressed into a single data. Then forward the compressed data to the base station or sink for further analysis [106]. As mentioned before, target tracking can be for either discrete objects or continuous objects. Aggregating continuous objects' data will not produce the correct answer due to active nature of the object. On the other hand, data aggregation can be applied on the discrete objects where the aggregated data can be used as the exact value because of the discrete nature of the objects.

5.7 Object recovery position estimation

There are number of researchers in literature that have worked on estimating the next position of an object [107], [30], [108], [60], [36], [54], [109], [62]. Position estimation is used to cut down the number of sensor nodes that are used for monitoring or reporting the information near the lost object. According to literature, position estimation is commonly based on Kalman filter KF, Particle filter, PF [30] and Extend KF [36] methods. The work in [107] chooses a node by considering the residual energy and spatial correlation of the sensor nodes located at different locations within the sensing range of the node. Thus, it balances energy consumption with accurate position estimation that ensures tracking reliability with optimal sensor nodes. Table 5 summarizes and compares the limitation and the objectives of the challenges above.

Table 5. Summary of Research challenges

Challenges	Objective	Limitation	Level of impact
Energy reservation	Is to prolong the network life	In the absence of energy reservation, the network will die soon.	High
Object detection	To have an instance detection of an intruder on the spot.	The lack of instance detection of object can lead to catastrophic in some application, e.g., Rescue operation	Low
Object speed	To have a protocol that can adapt to the changes of the target speed, to keep the target on track.	Due to the dynamic nature of object spend it is difficult for monitory mechanism to adapt.	Medium
Accuracy in Tracking	To provide high accuracy in tracking, it will reduce the number of sensor node participating the network.	If the accuracy of tacking being wrong, it cost the network of loss high energy without locating the object?	High
Sensor node collaboration	To have collaboration between sensor nodes, it helps increase the network life and reduce energy overhead.	If nodes are not cooperating, there will be no commutation, and this will have led to severe problems is some application.	Medium
Data aggregation	To provide a protocol that can aggregate, non-discrete object by keeping the information same or close.	Aggregating discrete object reading is almost accurate. However, the mechanism can accurately aggregate continuous object reading with the same level of accuracy.	Low
Object recovery position estimation	To have an object recovery scheme that is dynamic can recover one or many objects with important performance level.	Inaccuracy in object recovery is time-consuming and energy. Predicted Location might not have the target, and the node in the location will turn on for the search if not found then all nodes will turn on for the search. Object recovery is significant in the application that is time sensitive.	Medium

6 Future Directions

Despite the work that has addressed many research issues in OTSN, there are still issues that need further improvement. The OTSN open issues are discussed in the following subsections. The purpose of this section is to serve as guidelines for new researchers.

6.1 Communication failure

The communication failure in object tracking is one of the issues that need to be improved [110]. During object tracking, sensor node energy drained that result in the creation of coverage holes. Coverage holes create a barrier from one part to another part of the network. Moreover, target velocity and direction is an issue in network communication. When the velocity of the object or direction keeps on changing time to time, it affects the network communication. Therefore, there is need to have a network protocol or algorithm that can adapt the changes in the network structure to mitigate the number of communication failures.

6.2 Cross-layer integration

Energy consumption is a significant issue in OTNS. Cross-layer, integration of WSN layers is an energy saving approach; it cuts down the number of overhead because data is shared between layers [111]. Researchers have proposed many cross-layer integration protocols; however, the existing models are application-specific, and they cannot be used in different applications. Hence, there is a need to have a cross-layer integration, a protocol that works across many OTSN applications.

6.3 Object prediction delay

Researchers have proposed many works for prediction of the object [107]. However, the time that prediction algorithm takes to process or predict the future position of the object is not negligible. Many applications of OTSN are time sensitive (e.g., rescue mission, military combat, surveillance, forest fire, Volcanoes, and Earthquakes.) and minimizing the time taken to process the missing object position is necessary.

6.4 Hybrid network type

Hybrid network type can increase the over performance of OTSN regarding (accuracy, energy consumption, and cooperation). Data collection process can enhance, and energy consumption can be minimized. Combining two of the network types, e.g. (cluster with either face of the tree). Thus, the advantages of each network type can be combined now, which has more advantages compared to single network type. Hybrid network type can fit into future needs in OTSN.

6.5 Prediction accuracy

Accuracy in the prediction of the object location is one of the issues that can considerably increase or reduce energy consumption [3], [112-116], [41]. After predicting the location of the mobile object, the nodes that are in the predicted location should go to active mode and search for the object. However, when the prediction is not accurate, the energy of those nodes are wasted, and the object will not be found. Worse than this, all the nodes must wake up and search for the object that results in lots of energy consumption.

7 Analysis and comparison

This section compares and analyzes the OTSN presented in the taxonomy depicted in Fig. 3. Table 4 shows the comparison of an algorithm for OTSN based on the classification presented in the taxonomy.

Looking at Fig. 6, 60% of researchers have used cluster-based networks are used by 60% of the researchers for object tracking.

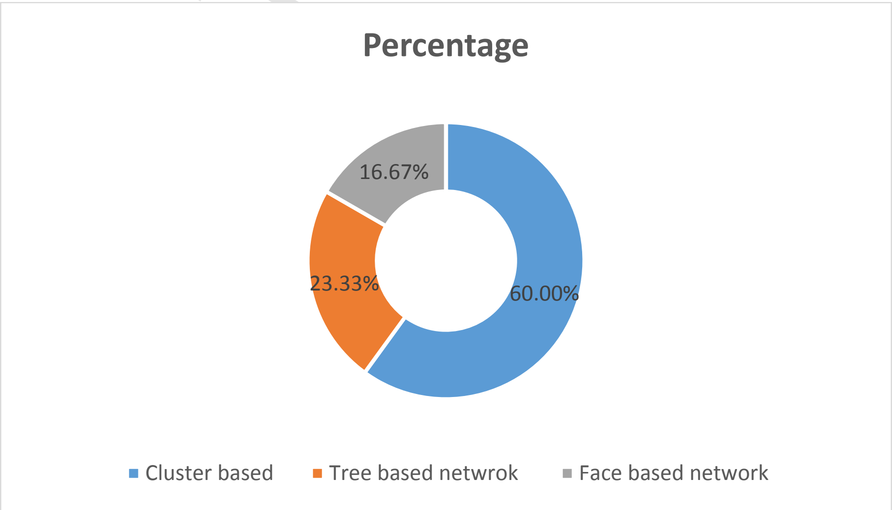

Fig. 6. Percentage.

Because of the advantages, it has over the rest such scalability, energy efficient and adaptable; hence, a single, multiple, discrete or continuous object can be tracked using this topology [117]. Also, because continuous objects expand in shape and size, which require many faces to track and monitor, face-based network, would be efficient in case of tracking a discrete object. Finally, tree-based networks would be suitable to monitor discrete object with constant speed.

In the object type, two types are considered: discrete and continuous. (a) Discrete object type allows the tracking object to be discrete where the sensor will detect the object and forward the data to other nodes [36]. Furthermore, (b) continuous object type [118], [41], [43], Fig. 7, shows many researchers used discrete objects rather than continuous objects. Because of the challenging nature of the object. Base on the Fig. 7, we can say the cluster-based network is most suitable for continuous object tracking. Furthermore, nodes in cluster-based methods are group together, so that only the clusters that detect the continuous object will participate in the tracking.

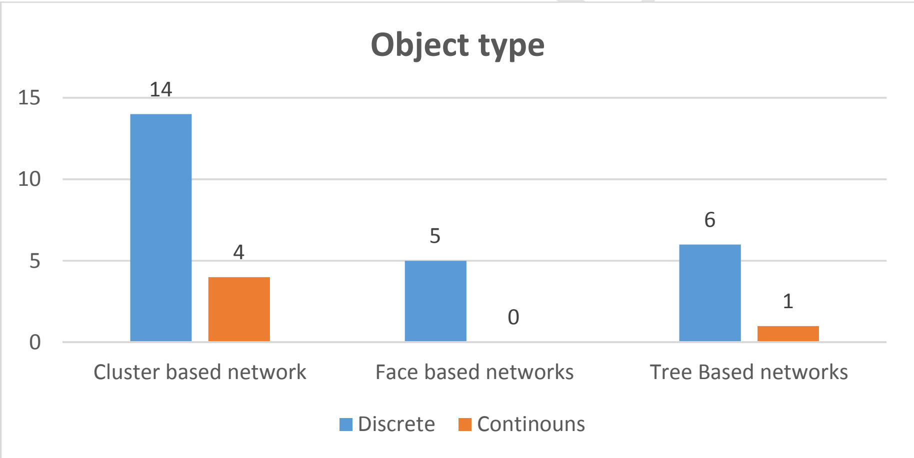

Fig. 7. Object Type.

A number of the object in OTSN is also profoundly influenced by the message reporting. Fig. 8 shows that single object tracking has 12 published articles while having 5 in Face based and 4 in the Tree-based network. The single object it has minimal computation and consumes relatively low energy compare to multiple objects.

Object recovery is one of an essential task in object tracking. However, based on our knowledge few type of research adds object recovery mechanism. Fig. 9, shows that cluster base has zero number of object recovery mechanism, On the other hand, face and tree-based networks has two and one article respectively based on discrete object recovery in all the three networks [3], [119], [22], [30] and no object recovery mechanism were proposed in a continuous object recovery.

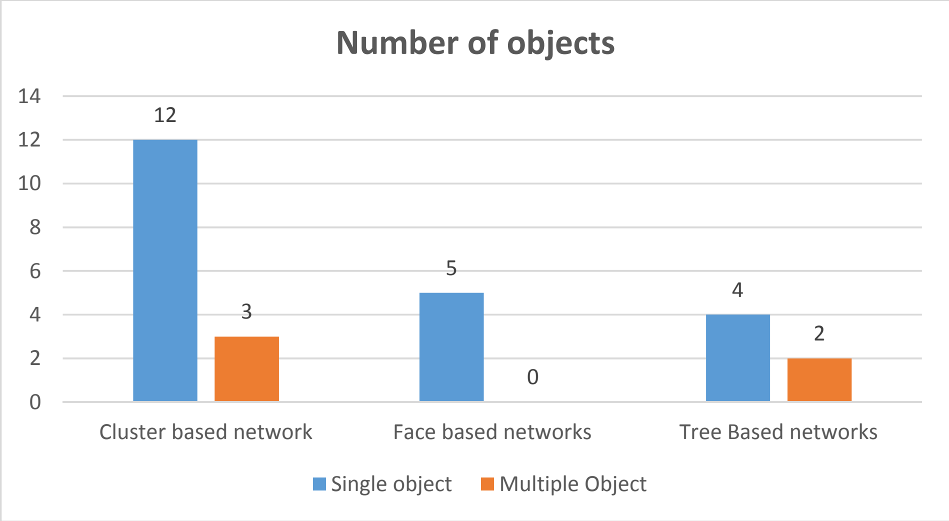

Fig. 8. Number of Objects.

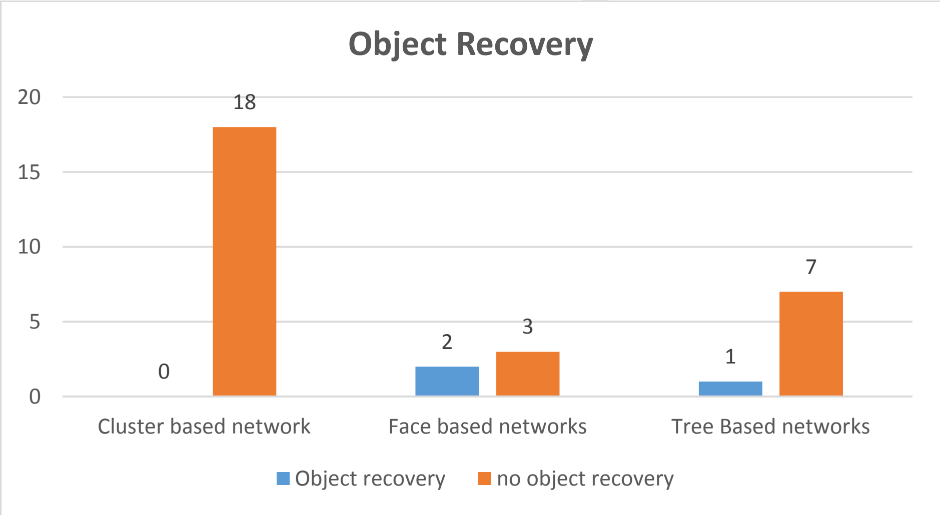

Fig. 9. Object Recovery

Energy efficiency is an important parameter that determines whether the nodes are consuming high energy. In Fig. 10, shows the number of published articles that are energy efficient, cluster-based network has the highest number of papers that are energy efficient [117], [121], [122], [56], [87], [106] followed by the tree-based networks [123], [124]. The methods are energy efficient only in situations where the target speed is constant. Lastly, face based network has the least number of energy efficient published articles.

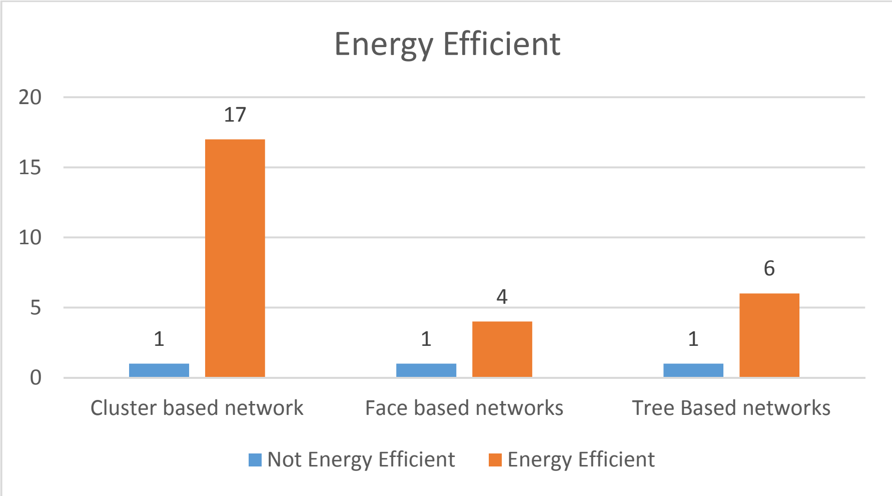

Fig. 10. Energy Efficient

Regarding object prediction, as can be noted from Fig. 11, and Table 4, twelve published articles of the clustering target tracking mechanism do not use prediction mechanisms, while only six published articles used prediction [125], [89], [32], [94] that provide prediction mechanism that will minimize object prediction missing rate.

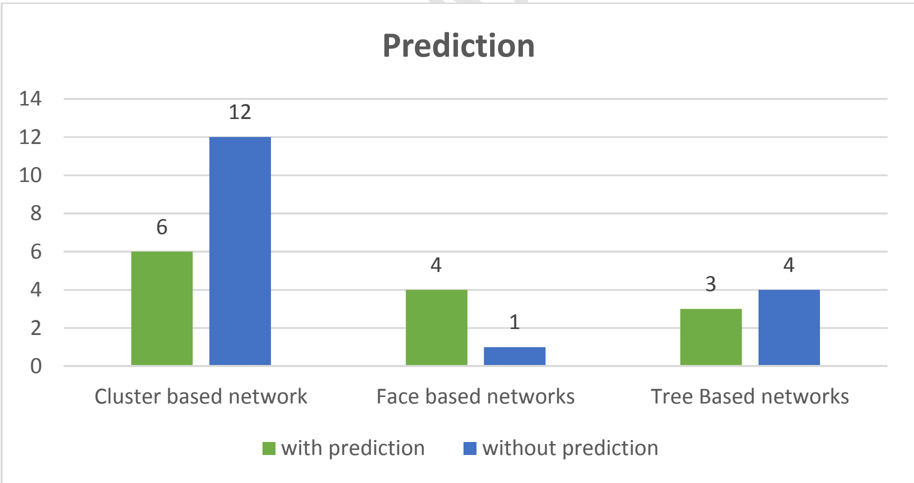

Fig. 11. Prediction

8 Conclusion

In this study, the most recent works on monitoring and tracking objects in smart cities using WSN are studied. Target tracking has been an area that received a considerable amount of attention by researcher because of the importance of its application in different fields such as military, environmental, habitat monitoring, home or office application and others. Therefore, in this paper, we have identified and reviewed the new OTSN algorithms used in the smart city. We have categorized OTSN concerning network type, type of object, type of sensor, number of the object(s) and object recovery. Despite the

significant research works in the area, there are still several technical challenges in OTSN that should be addressed.
OTSN has the potential to drive this domain by providing solutions to different types of smart cities applications, though still, it is in its early ages. The potential difference that it can provide will give opportunities to researchers across the domain. Hence, we have discussed the technical challenges in object tracking, location prediction, and recovering. Finally, the presentation of open research issues to provide new researchers a sense of direction in the domain.

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Highlights

- One of the most interesting applications of wireless sensor networks in smart cities would be detecting and monitoring or tracking of objects based on object tracking sensor networks (OTSN).
- The review delineates the advantages as well as the weakness of existing OTSN and conduct a comparative view.
- Furthermore, research challenges in OTSNs and existing methods are investigated with a focal point of energy constraints, object detection, object speed, tracking accuracy, sensor node collaboration, data aggregation and object recovery position estimation in WSN and smart cities.
- Open research issues that required further improvement are summarized.