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Investigating RFID Tags Fusion in a Clustered WSN Applied to Vehicle Identification and Tracking

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Abstract-**Due to major advancements made to RFID technologies, various types of applications involving vehicles have been deployed such as automatic toll gate payment, fleet management, safe navigation and intelligent transport. Most of these applications integrate a vehicle identification process using an RFID tag. When tracking becomes an application requirement, it is common to use GPS positioning to localize the vehicles. However, depending on the area where the vehicle is located, accuracy may not be adequate, in addition to the high cost of the GPS receiver. In this paper, it is proposed to investigate, at a system level, the integration of RFID technology and clustered wireless sensor networks WSN in order to identify and track vehicles, as an alternative to a GPS-based system. The WSN is designed using smart nodes which integrate an RFID reader and a wireless communication interface. This paper analyzes the benefits of using a time-slotted approach and data fusion performed at the node level on the system throughput expressed as the number of vehicle tags read per second. Two metrics energy*delay and throughput are used to evaluate the proposed fusion schemes. When deployed in desert-like regions, solar panels are recommended to avoid CH (cluster head) election. Simulation results clearly show when it is recommended to use RFID tag fusion and when it is not. Finally some avenues are presented for future research.**

Keywords: RFID, WSN, tag fusion, and solar energy

1. INTRODUCTION

Nowadays, wireless sensor networks (WSN) are widely used in various types of applications; survey and taxonomy of WSN are presented in [1]. Each sensor node is a low performance computer with limited computing and communication capabilities. It is usually operated with a tiny battery. The network lifetime is mainly affected by the targeted application and capacity of the battery. Hence, minimizing communications among the nodes is one of the essential requirements in designing a network of wireless sensor nodes [2]. When Radio Frequency Identification (RFID) technologies are coupled to WSN, new features are provided such as tracking, identification and localization. An RFID tag is incorporated into the object to be tracked or localized using radio signals. Among the various applications that can benefit from RFID-based localization and tracking technologies, vehicle identification and tracking appears to be a promising field [3]. An RFID tag is attached to a vehicle which is identified as soon as it enters the RFID reader's range. The data stored in the tag's memory is captured by the reader and transmitted to a server through a public or private network. Figure 1 shows a generic view of an RFID-based vehicle identification and tracking. Depending on the density of vehicle traffic, the number of RFID tags to be transmitted to the server can be very high which may result in congestion and high transmission delays. This issue can be addressed by removing unnecessary information and using data aggregation schemes. In our research work, it is proposed to aggregate vehicle RFID tags into packets which are then routed to a sink node through a clustered WSN while decreasing communications between nodes and related cluster head. Two metrics are analyzed: energy*delay and system throughput which are critical factors in any vehicle localization system using an RFID-based WSN.

This research paper is structured as follows: section 2 present a survey of the most relevant research works related to clustered WSN and fusion techniques; section 3 presents the proposed methodology; section 4 presents the results and section 5 concludes the paper.

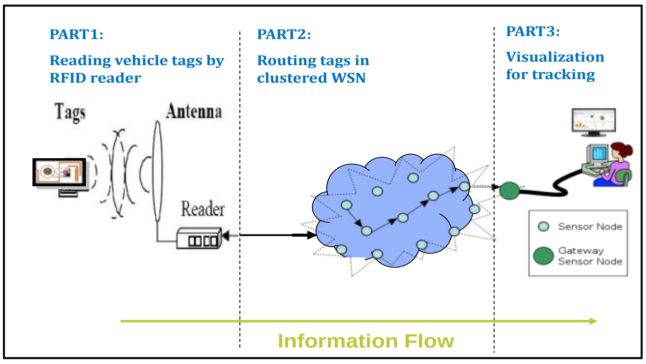

Figure 1: The complete project, our work is in part 2.

II. RELATED WORK

In [4], authors proposed a maximum lifetime data aggregation (MLDA) algorithm which finds data gathering schedule provided locations of sensor nodes and base-stations, data packet size, and energy of each sensor node. A data gathering schedule specifies how data packets are collected from sensor nodes and transmitted to base stations for each round. A schedule can be defined as a collection of aggregation trees. In [5], a heuristic-greedy clustering-based MLDA based on MLDA algorithm is proposed. The network is partitioned into clusters and referred each cluster as a super-sensor. The maximum lifetime is then computed and scheduled for the super-sensors. The resulting schedule is used to construct aggregation trees for the sensors as well. In [6], a two-phase clustering (TPC) scheme is described. In phase I, clusters are created with a cluster-head and each node within that cluster connects directly to the cluster-head. The cluster-head rotation is localized and is done based on the remaining energy level of the sensor nodes. This reduces time variance of sensors and leads to energy saving from unnecessary cluster-head rotation. In phase II, each node within the cluster searches for a neighbor closer than the cluster-head. This neighbor is called a data relay point and a data relay link is set up. This new relay link allows sensor nodes within a cluster to communicate with the cluster head in addition to the original direct link leading to energy savings. The data relay point aggregates data at forwarding time to another data relay point or cluster-head. In case of high network density, TPC phase II will setup unnecessary data relay link between neighbors as closely deployed sensor will sense same data and this lead to a waste of energy [7]. Data packet can be aggregated with the help of lossy or lossless aggregation schemes. Lossless ones ensure a complete recovery of all individual sensor data at the base station [8]. In [9], they used data aggregated to maximum the lifetime routing for WSN. In the proposed research work, tags are aggregated at the sensor level to produce packets. These packets are routed to CH using Zigbee technology (see figure 2). In Figure 3 and 4, we present cluster-WSN algorithms and system blocs respectively [10].

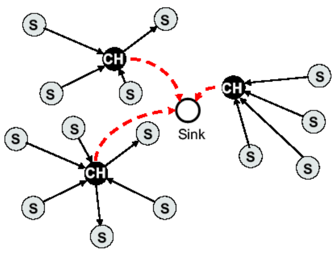

Figure 2: Clusters in WSN.

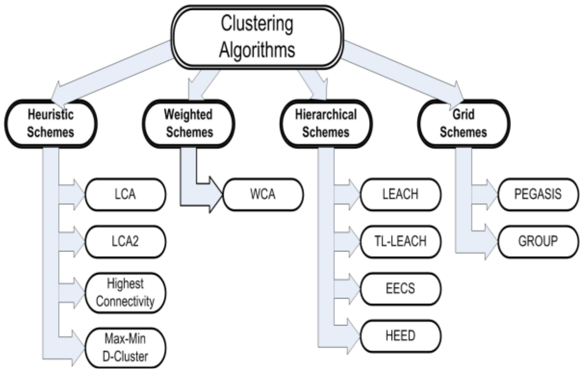

Figure 3: Classification of clustering algorithms

To support scalability, nodes are often grouped into disjoint and mostly non-overlapping clusters. Clustering algorithms are compared based on metrics such as convergence rate, cluster stability, cluster overlapping, location awareness and support for node mobility. Low-energy adaptive clustering hierarchy (LEACH) is able to perform local fusion of data in each cluster to reduce the amount of data that transmitted to the base station. In LEACH, each CH directly communicates with BS no matter the distance between CH and BS. It will consume lot of its energy if the distance is far. TL-LEACH uses two levels of cluster heads. HEED operates in multi-hop networks, using an adaptive transmission power in the inter-clustering communication. EECS introduces a weighted function for the plain node to make a decision, that which proper cluster should be joined. Based on the constraints related to our application, it is suggested S-LEACH, where the CH in LEACH is equipped with solar panels. The following figure depicts the general flow process of the system.

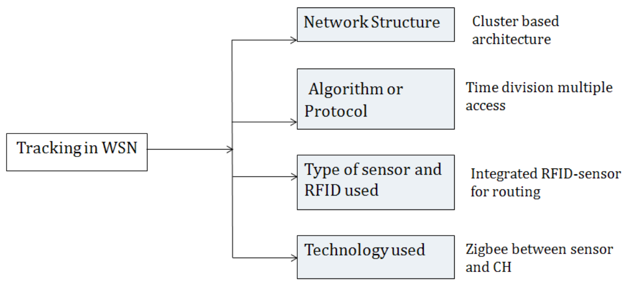

Figure 4: WSN-RFID System blocks for vehicle traffic monitoring & tracking

III. METHODOLOGY

We consider a field containing *M* randomly deployed sensor nodes, divided into *C* geographic clusters. Without any loss of generality, we assume that Cluster 1 contains *N1*nodes; Cluster 2 contains *N2* nodes and so on.Figure 1 and 2 show that each sensor node within the WSN is integrated with an RFID reader to detect vehicles. Theses nodes are called smart nodes. Data fusion is performed at sensor nodes by generating single *k*-bit packets from multiple incoming tags [11,12,13,14]. In our research work, we addressed the following issues:

- Powering the CH.
- Communication protocols between the CH and its sensor nodes.
- Data fusion schemes.

A. Powering the cluster head

When using clustering, identification of the cluster head is done through election. However, electing a cluster head may be compromised by two main issues:

1) It may happen that during the election of the cluster head (CH), and due to low energy levels, no CH is elected. Consequently, the network goes down although there are still nodes alive.
2) During the rotation for CH, some packets may be dropped [15,16,17,18].

The power issue can be addressed by using high-rated batteries to avoid frequent replacement or solar panels when considering implementing a WSN in a desert-like region in order to increase network lifetime. Table 1 shows the energy provided by a typical AA battery or solar panels.

Energy Source	Energy
AA battery (1.5 V, 2300 mAh)	12420 Joules
One square meter panel of solar cells *(30% efficiency, 4 hours of direct sunlight exposure per day)*	4.32 MegaJoules/meter /day

Table 1: Comparison of energy sources

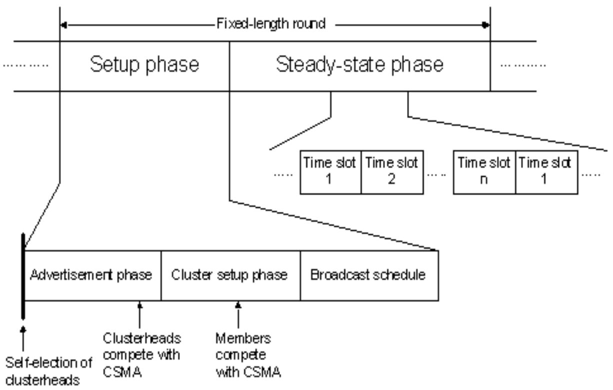

Figure 5: TDMA protocol with CH elections without solar energy

In figure 5, if we equip the CH with solar panels, then the setup phase will be eliminated and the CH becomes permanent.

B. Random TDMA protocol

A Slot time interval is allocated randomly to each sensor node for transmitting its packets. We use random TDMA protocol between sensor nodes and their CH. The node transmits data to the cluster head within a slot time interval. The number of slots is based on the length of the packet [19]. The total time required by all sensor nodes within a cluster to transmit constitutes a frame as shown in figure 6.

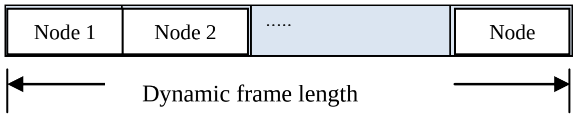

Figure 6: TDMA for a cluster without CH elections with solar energy

C. Transmission schemes

In a WSN, energy is mainly consumed by frequent communications between nodes within a cluster, including the CH. This is due to the need to exchange information between various nodes. In car traffic monitoring and tracking applications, the main data units exchanged between the CH and its neighbors are the vehicles RFID tags in addition to some control information. The format of a passive RFID tag is shown in figure 7.

Figure 7: Structure of EPC type 1 Passive RFID tag (96 bits) [20].

Without fusion, for each car captured by the RFID reader, a packet will be sent to the CH with the following information in bits:

WSN ID (16), Time (16) and RFID tag (96).

In order to decrease the amount of information exchanged between the sensor nodes and the CH, it is proposed to aggregate *K* RFID tags captured by the RFID reader into a single packet sent during a slot time rather than forwarding all RFID tags separately [21].The difference of packets is shown in figure 8 and 9.

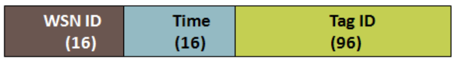

Figure 8: Packet payload format (without fusion)

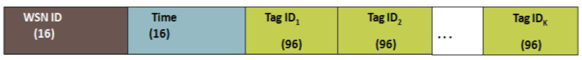

Figure 9: Packet payload format (with fusion)

If we assume that k tags are available, the total number of bits sent to the CH is given by:

- Without fusion: $N_1 = k \times 128$ bits.
- With fusion: $N_2 = 32 + k \times 96$ bits.

The theoretical percentage of bits that are saved when using fusion is given by:

$S = \frac{N_1 - N_2}{N_1} = \frac{k \times 32 - 32}{k \times 128}$. Under our assumptions, the maximum value of S is given by: $S_{k\to\infty} = 32/128 = 25\%$. This result indicates that substantial energy savings can be achieved when using tag fusion and batteries.

D. Simulation Model

In order to simulate the exchange of packets between the sensor nodes and the CH, We will use frame time division TDMA within the cluster. Each sensor is allocated up to 5 slots. One slot time is estimated to 0.01 sec [22, 23].

To estimate the total energy consumed by the cluster, we will use the energy model presented in [24]. The communication energy parameters are set as:

Eelec= 50 nJ/bit and Eamp = 100pJ/bit/ m^2. Thus to transmit and receive a k-bit packet with distance d, the radio expends:

Sending energy: Es = (Eelec +Eamp*d^2)*k (1)

Receiving energy: Er = Eelec*k (2)

Fusion energy: Ea = Er/ 10 (3)

Where d is the average distance between CH and its sensor nodes. Each sensor node has a data buffer of 2740 bits. Figure 10 shows the abstract model used for both systems (with and without fusion) to compute the number of packets sent, the energy consumed and the estimated delay for 24 hours of simulation time. The main input/output parameters are presented in table 2.

Input data	A	Arrival rate of vehicles: 6, 30, 48, 120 Vehicles/minute
	B	Max buffer = 2740 bits
	d	Distance between sensor and CH (= 50m)
	N	Number of sensors per cluster = 5, 6,…, 30
	E_i	Initial energy of each sensor is 150 Joules
	E_m	Minimum Energy
	X	E1 +E2*d^2
	Eelec	50 nJ/bit
	Eamp	100 pJ/bit/ m^2 = 0.1 nJ/bit/m^2
	Slot	0.01 second
Output data	K1	Total number of aggregated tags
	K2	Total number of non-aggregated tags
	D1	Total delay of tags during simulation with fusion
	D2	Total delay of tags during simulation without fusion
	Bit1	Total number of bits sent to the CH with fusion
	Bit2	Total number of bits sent to the CH without fusion
	Ec1	Total energy consumed with fusion
	Ec2	Total energy consumed without fusion
	Z1	Average(energy*delay) for with
	Z2	Average(energy*delay) for without

Table 2: Input/output parameters

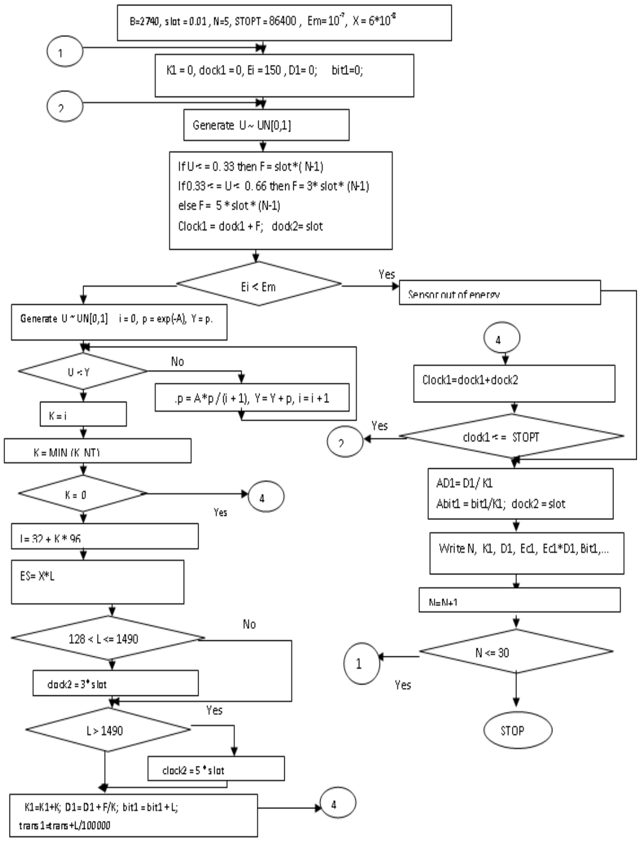

Figure 10: Abstract simulation of fusion model for various vehicle arrival rates A.

IV. SIMULATION RESULTS

The following figures are used for the evaluation of the two models with respect to output parameters presented in table 2. Different cluster sizes and arrival rates are used. Simulation results are validated using replications and tolerance factor of 5% [25,26]. Figure 11 shows the programming environment of our simulation with validation. For all the following figures, solid lines show results when fusion is used, while dashed lines show results when fusion is not used.

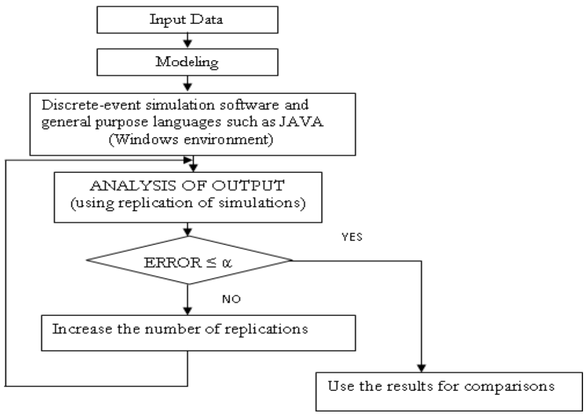

Figure 11: Programming environment and validation with α = 0.05 and 10 replications

A. Energy consumed delay*

The total energy consumed by a sensor node is given by:

EC1= ES + ER + EA (4)

EC2 = ES +ER (5)

Where ES, ER and EA are the energies consumed by a sensor node for transmission, reception and fusion respectively (see equations 1, 2 and 3). We want to analyze the variation of the metric Z [27] given by:

Z1 = (EC1 * D1)/K1 (6)

Z2 = (EC2 * D2)/K2 (7)

We apply Poisson distribution with different rates cited above to generate a random number of tags per sensor node. The values 6, 30, 48 and 120 cars/min have been generated randomly in order to model traffic intensity in United Arab Emirates. These values are quiet similar to data provided by online system such as the DGT Traffic Map in Spain (http://infocar.dgt.es/etraffic). While the number of cars in Spain is much larger compared to UAE, the selected values can be considered (as a first-order model) good enough to model traffic intensity in UAE.

Experiment j	D1	EC1	K1	Z1
1	6157.34533	39.024522	50285	4.846364
2	6161.24933	39.021988	50276	4.850260
3	6156.01467	39.053837	50327	4.845608
4	6161.01048	39.01977	50276	4.849846
5	6154.81467	39.043192	50314	4.844069
6	6156.17467	39.034259	50295	4.845965
7	6159.36533	39.026993	50285	4.848152
8	6156.27067	39.052612	50325	4.845302
9	6160.37867	39.033266	50294	4.848903
10	6159.884	39.04617	50307	4.848804
The mean	6158.250782	39.035661	359.600000	4.847328
The variance	5.655860	0.000159	10.865958	0.000005
Half width: W	1.362723	0.007226	0.00021603	0.001219
E= W/mean	0.000221284	0.0001851	0.02160299	0.000251
Error (%)	0.022128407	0.018511	359.600000	0.025153
Interval: mean ± W	6156.888059	39.028435	50287.53404	4.846108
	6159.613505	39.042887	50309.26596	4.848547

Table 3: Sample output of the validation process for data fusion with N= 20 sensors

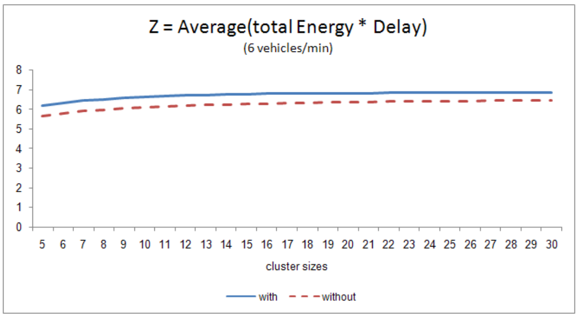

Figure 12: Energy*delay (A = 6vehicles/minute)

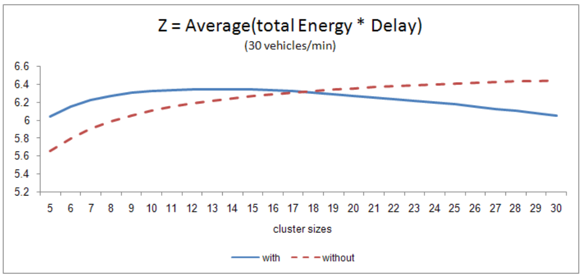

Figure 13: Energy*delay (A = 30 vehicles/minute)

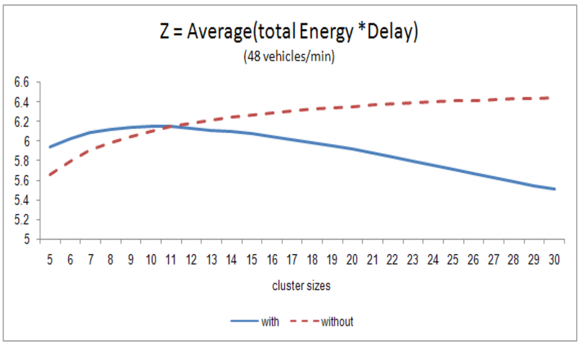

Figure 14: Energy*delay (A = 48 vehicles/minute)

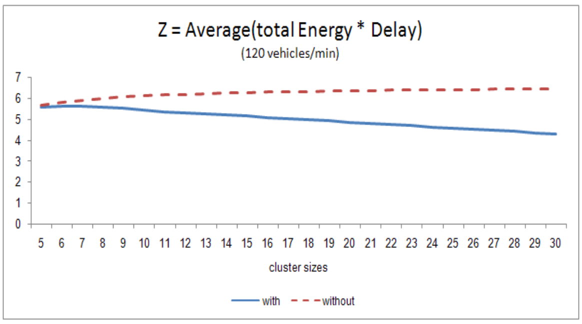

Figure 15: Energy*delay (A = 120 vehicles/minute)

Figures 12, 13, 14 and 15 are used for to measure the average of (delay * energy) of each model for different car rates: 6, 30, 48, and 120 vehicles/min respectively. A comparison is established between tag fusion and without fusion.

When the car traffic rate is low, regardless cluster sizes, the model of without-aggregation has better performance.

When the car traffic rate is high, regardless cluster sizes, the model of with-aggregation has better performance.

B. Throughput

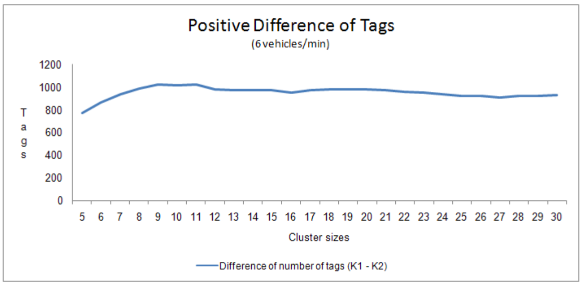

Figure 16: Positive variation of difference of tags (K1 – K2) (A = 6vehicles/minute).

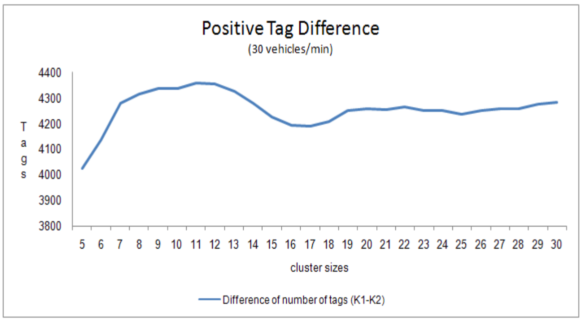

Figure 17: Positive variation of difference of tags (K1 – K2) (A = 30 vehicles/ minute).

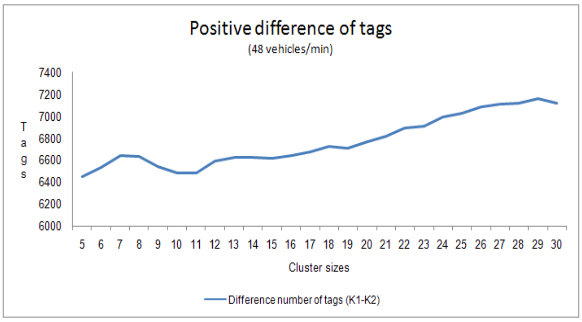

Figure 18: Positive variation of difference of tags (K1 – K2) (A = 48 vehicles/ minute).

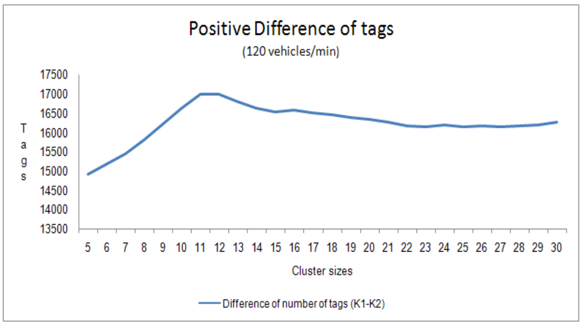

Figure 19: Positive variation of difference of tags (K1 – K2) (A = 120 vehicles/ minute).

Figures 16,17, 18 and 19, are used for to measure the total number of tags/car sent for different car rates: 6, 30, 48 and 120 vehicles/ min respectively. A comparison is established between the 2 models, tag fusion and without fusion. Regardless the car traffic rates and cluster sizes, the model of with aggregation is sending more tags to the cluster head, this yield less car losses of tracking.

C. Gain and energy consumed

The gain in term of average number of bits sent to the CH is defined as follows:

Gain = (1- Abit1 /Abit2)*100 (8)

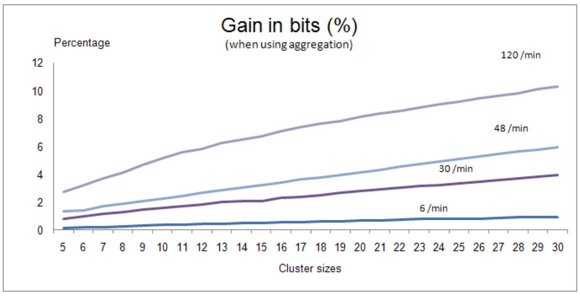

Figure 20: Positive gain on the average number of bits sent for all car traffic rates

Figure 20 shows that for all cluster sizes and arrival rates, tag fusion has a positive gain in term of average number of bits sent to the cluster head. For instance, cluster size = 30, arrival rate = 120/min, the gain is 10%.

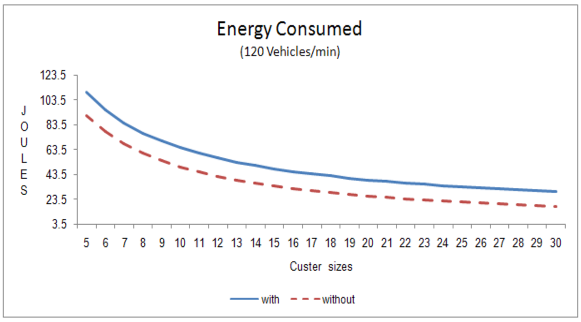

Figure 21: Energy consumed during 24 hours for 120 vehicles/ min for all cluster sizes

From Figure 21, we remark that the maximum energy consumed during 24 hours is 110 Joules. If we place 2 batteries (AA battery (1.5 V, 2300 mAh) at every sensor, the initial energy will be 49600 Joules [28]. Hence the life time of the sensor is 49600/110 = 445 days of operation.

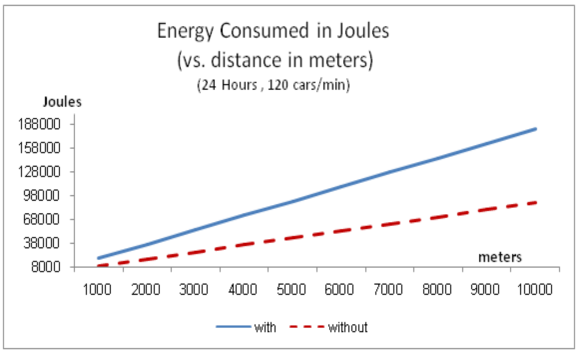

Figure 22: Energy consumed during 24 hours for 120 vehicles/ min for various distances *d*

From Figure 22, when 2 AA batteries are used, the maximum distance between the node and the router is no more than 2.5 Km/Day. If we use Xbee technology [29], solar energy can be used in order to route data directly to the sink or a CH located at far distances. Figure 23 summarizes the network with N clusters (5,…,30) and with different car arrival rates.

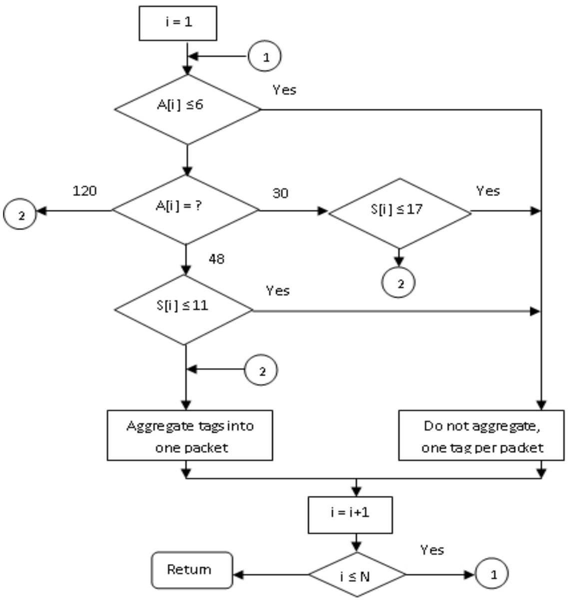

Figure 23 Summary for the entire network with N clusters

V. CONCLUSION & FUTURE WORK

In this research paper, we presented a new RFID tag fusion scheme at sensor node level for applications related to vehicle traffic monitoring and tracking. Simulation results showed that when the vehicle arrival rate increases, it is better to aggregate beyond a certain cluster size. Several metrics have been used in order to evaluate the proposed fusion scheme: energy, throughput, delay and a combination of delay and energy. In addition to that, it is recommended in desert-like regions to equip the CH with solar panels when using the LEACH clustering algorithm in order to avoid CH election. In this case the CH becomes permanent.

As a future work, it is proposed to study the integration of lightweight encryption and signature algorithms to protect tag information [30].

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