Deployment Model of Wireless Sensors Networks in the Framework of Hybrid Sensors and Vehicular Networks for Road Safety

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Abstract*: Hybrid Sensors and Vehicular Networks (HSVN) represent an architecture which creates a framework of collaboration between Wireless Sensors Networks (WSN) and Vehicular Ad Hoc Networks (VANET). The goal of this collaboration is the improvement of the road safety. The coverage and connectivity problems (deployment models) of wireless sensors networks represent a big challenges studied by many searchers. The environment and application requirements have a relationship with the aspects used to create a deployment model. In this paper, we have proposed a deployment model of WSN used in HSVN basing on the roads network and application of road safety. This model uses an algorithm which has for purpose ensuring the sensing of any road event and allows the connectivity between sensors. The results proven that our proposition is more reliable than others works.

***Index Terms*: Coverage, Connectivity, Deployment models HSVN, VANET, WSN.**

I. INTRODUCTION

In purpose to improve the road safety, many countries have worked to make their transport systems intelligent. The intelligent transport systems (ITS) [1] are systems basing on the use of new technologies and several networks types. There are several goals of creation of ITS where the improvement of road safety and the management of road traffic are the mains ones. With the creation of the intelligent vehicles, several collaborations have been defined between them and others networks like 4G [2] and wireless sensors networks (WSN). The collaboration between the vehicular Ad Hoc Networks (VANET) and WSN is called Hybrid Sensors and Vehicular Networks (HSVN) [3, 4]. HSVN represents a new architecture proposed in the few last years, allows to the two networks working gathering. This architecture aims to define a framework of collaboration between WSN represented by the sensors which are deployed in static way on the roads and VANET represented by the intelligent vehicles moving on these roads. HSVN is created to improve the road safety and make the management of road traffic more easily. The principal of work of HSVN is that when the sensors detect the roads events, they communicate between them to ensuring the arrival of these roads events (messages) to the sensors gateways (the sensors communicate with the vehicles). After, the arrival of messages to the sensors gateways, they save these messages in their databases. When a vehicle is inside the communication range of the sensor gateway, the exchange of messages between the two will have place. After that, the vehicle broadcasting and sharing these messages with the others vehicles. In addition, the collaboration created by HSVN, allows the improvement of the performance of two networks. First for WSN, the sensor energy represents a big disadvantage because the sensor has not rechargeable energy battery. One of the main causes which allow quickly the energy consumption of the sensors is the communication. For reducing the communication of the sensors, in HSVN, we can use the vehicles which have not the energy problem to disseminate the roads events detected by the sensors to a long distance. Second for VANET, it is a network represented by a dynamic topology i.e. the density and speeds of vehicles, change in the time. As consequence, we have usually a fragmentation problem into the VANET (disconnection problem). In HSVN, to ensure the communication between vehicles, we can use a subset of sensors as gateways between vehicles. As a vehicle communicates with a gateway sensor, it sends to it its messages. This sensor saves these messages into its database and when another vehicle is detected by this sensor, it sends to it the messages saved.

To create a HSVN network, the first key is the deployment model of WSN on the roads network i.e. the coverage and connectivity of the WSN on the roads network. There are many challenges to create this deployment model. A part of these challenges are linked to the environment proprieties and the application requirements and the rest of the challenges have a directly relationship with the sensors characteristics.

This paper presents the steps that we have followed, to create our deployment model of WSN used in the framework of HSVN. The paper is organized as follows: in section II, we present the related work used to create our deployment model. Then in section III, we give and explain each step followed to create this latter. In section IV, we present the simulation results, while the conclusion is presented in section V.

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II. RELATED WORKS

A. Coverage and Connectivity of Wireless Sensors Networks

The deployment of WSN on the road network represents a big challenge in HSVN for two reasons. The first reason, is that the deployment must allow the detection of any event taking place on the roads (coverage of WSN) while ensuring a low energy consumption of sensors [5].

The second reason, is that this deployment must allow to each sensor the transmission of the data collected by this latter to the Base Station BS (connectivity of WSN) [5].

For coverage of WSN, we distinct three different coverage types according to the environment and the application domain which are: area coverage, point coverage, and barrier coverage. The commons points between all these coverage's [6] that the coverage deployed must be ensured the monitoring of the phenomena which is the purpose of deployment of WSN in this environment. However, in the other hand, the number of sensors deployed must be optimal and the positions of these sensors must be chosen according to several factors as sensing ranges, communication ranges, environment nature, application requirements …. In our case, we interest to the area coverage. According to the application, we have full area coverage and partial area coverage. The full area coverage meaning that every location is covered by at least one sensor node. The partial area coverage meaning that the sensors cover a part of this entire area. In this case, a present is defined according to the application requirements. This present is more than 0 % and least than 100 %. In addition, we have two categories of coverage: 1-coverge (simple coverage) and k-coverage (k >1 multiple coverage). The choice of the coverage category has a directly relationship with application requirements.

The connectivity of WSN [6] represents that at in m moment, there is a least a path from the detector sensor to the sink i.e. the detector sensor can communicate directly with the Sink (one-hope connectivity) or indirectly (multi-hops connectivity). According to the environment, application domain, and the nature of sensors (static sensors nodes or mobile sensors nodes) we have two networks types of connectivity. First, permanent connectivity: means that there is always a least one path (simple connectivity) or several disjoint paths (multiple connectivity) from the detector sensor to the sink. This sink represents a static node. Second, intermittent connectivity: in this case, we have one or several mobiles sinks nodes which move to collect the data from the sensors nodes disconnected. In this type, the mobiles sinks can also collate the data only from the clusters heads (CHs) case of WSN repartees on clusters.

B. Analyze of Environment and Application Requirements

To define the coverage of WSN on the roads network, there are many challenges. These challenges are linked to two factors. The first factor is the environment contents these roads where the speeds and density of vehicles, change according to this environment. The vehicle represents the important actor because all the data collected and processing by the WSN, will be sent to the vehicle. The end-to-end delay metric in WSN has a relationship with the vehicle speed and vehicle density i.e. each time, the vehicle speed increases this delay must be smaller and each time the vehicle density is low the sharing and the broadcasting of the data collected by the sensors will be more difficult . We can define three different environments: urbane environment (Cities), rural environment (Secondary roads) and roads of high speeds (Highways). The second factor is the roads proprieties e.g. the trajectories types, the number of the ways in the road, the direction of the road, number of intersections in the roads of urbane environment, the present of obstacles in the road…. Each road has different proprieties according to others roads. These proprieties have a relation with the environment and the area geographic. However, logically, the position and the number of sensors will be changed according to the environment type and the road properties. However, the position and the number of sensors also, have a relation with the sensor proprieties. We can have homogeneity sensors (all sensors have similarly proprieties as the sensing ranges, communication ranges, storage and processing capacities…etc.) and heterogeneity sensors which have not similarly prosperities. Also, according to the sensor role, there are three types of sensors: sensors used only for data routing, sensors used only to sensing the roads events, or sensors have the both two roles (sensing and routing). The most of applications used for road safety in the framework of HSVN, have for purpose to ensure two metrics. The first metric is: real time delivery of roads messages to the vehicles, in the case of warning messages and the transmission of the message concerned the road traffic information to the vehicles, in small delay time. The second metric is: the energy consumption economy of the sensors for extend the lifetime of WSN. To ensure a weak energy consumption of sensors, it is necessary that a set of sensors will be inactivated at time periods i.e. the sensors will be at sleeps time periods.

Many deployments algorithms [6] have been proposed, in the purpose to find a solution to the problems of coverage and connectivity of WSN. There are two categories of algorithms: centralize algorithms and distribution algorithms according to the WSN application. Furthermore, through to the principal of work of these algorithms, we have two classes. The first class of algorithms: is algorithms basing on the relationship between the sensing rang r and communication range R. In this class, the relationship between r and R defines the full coverage area with k-coverage ($k \geq 1$) and starting to the coverage area type we can ensure the connectivity of WSN. The second class of algorithms: is algorithms basing on strategy. To ensure coverage and connectivity to both, we use a strategy. There are three strategies: the forces-based strategy, the grid-based strategy, and the computational geometry-based strategy. IN our case, we have focused on the study of the algorithms of the first class. Staring to the results of our studies, we have proposed our Sensors Localization Algorithm (SLA).

C. Problematic and Contribution

We can conclude that to create a deployment model, it must take in consideration the environment, the roads properties, and the metrics used into the road safety application. In addition, the deployment Model in our case is deterministic sensors deployment. The problematic that the most of proposal deterministic deployment models basing on the relationship between r and R [6] are referential models i.e. they have been proposed for a regular environment. In our case, we have tried as much as possible to create a deployment model closely to

the real environment (irregular environment). In the following section, we will explain the way used to create our deployment model while taken in consideration the challenges presented into the previously subsection.

III. PROPOSITION OF DEPLOYMENT MODEL OF WIRELESS SENSORS NETWORKS

A. Roads Network

Study of geographic environment: We can say that a geographic area is a set of roads. The area can be covered three different geographic environments (subsection II.B). The vehicles speeds change according to the environment (Table I). Similarly, the roads proprieties change form road to another road (subsection II.B). From, the geographic study of roads and the statistic of roads crash, we have defined road classes. This classification contents three classes' types. Each class is represented by a colour which gives the danger degree. An example of classification of a road is presented in the table II. As coverage established by the wireless sensors networks on road network, is based on the position, the distance between sensors, and its number on road, we will take into consideration the environment geographic and the road classes (Tables I and II) for definition these proprieties.

Table – I. Speeds and Density of Vehicles According To the Environment

Environment	Speeds interval (Km/h)	Vehicles density
Urbane	20 - 60	High
Rural	60-100	Low
Highway	100-140	middle

Table – II. Example of Classification of Roads

Road	Trajectories	Direction road	Ways number
Gree n	good	One direction	More than two
Oran ge	Between good and bad	One direction	More than two
Red	bad	Two directions	Equals two

Road segmentation model: In the purpose to make the deployment operation of sensors on roads more easily and according to our study in the previously subsection, we have proposed a segmentation model. This model allows the decomposition of roads of a geographic area to a set of segments. We associate to each segment i a risk factor RFi. The values of RFs are chosen relative to a study made on statistic on the geographic causes leading to the roads crash. The way that we have used to calculate a segment length (SL) in meters, is defined into (1). The Table III gives an example of interval of risks factors of segments of different environment. The distance between the sensors has a relationship with the sensing range r and communication range R of sensors. We suppose that R equals or more than r ($R \geq r$). The sensors use IEEE 802.15.4 as MAC protocol [7]. We have chosen this MAC protocol because many searchers [7] prove that this protocol is matching with the static sensors deployed on the roads. The distance between the sensors, equals r (sensing range) multiples by RFi of segment i. For example, the maximal distance (when the RFi equals to 1) is r metre and the minimal distance (when the RF equals to 0.8) is $0.8 \times r$ metres. The distance has a direct relation with the RFi. The distance is decreased when the RFi is down and vice versa. We have thought to this concept because typically, the sensors can communicate (connectivity) more powerfully between them when they are closer and the coverage becomes multiple (k-coverage with k >1). Our segmentation model is defined by: an area is composed of n roads (from the 1st road until the neme road). A (Ri) road can be green, orange or red. For each (Ri) road, we have decomposed it according to its length to segments of the similar lengths (starting of the 1st segment until the meme segment). The way used to calculates segments number into Ri road (Segment number (Ri)) and A area (Segment number (A)), is defined into (2). The localization of a road event on geographic area is defined by: [The area number. The road number. The segment number] (Ai.Rj.Sk) where Ai is the geographic area number, Rj: is the road number in this Ai area, and Sk: is the segment number in the Rj road. This notation makes the localization of a road event more easily on the environment monitored by the WSN

$$SL = R \square 10$$

Table – III. Roads Segmentation

Environment	Class	RF interval of segment
Urbane	Green	0.90-1.00
	Orange	
	Red	
Highway	Green	0.85-0.95
	Orange	
	Red	
Rural	Green	0.80-0.90
	Orange	
	Red	

$$\begin{cases} Segment_{number}(Ri) = Road\ length\ (Ri) \div SL \\ if\ (Segment_{number}(Ri)\ is\ not\ entry\ number)\ then \\ Segment_{number}(Ri) = Segment_{number}(Ri) + 1 \\ Segment_{number}(A) = \sum Segment_{number}(Ri) \quad i = 1 \ldots n \end{cases} \quad (2)$$

B. Sensors Localization Algorithm

To ensure full area coverage of road events, the positions and the number of sensors, represent important factors to achieve this goal. From the subsection III.A.2, we have proposed a segmentation model of roads which allows making more easily the deployment operation of sensors on a geographic area and take in consideration the proprieties of environment and the road. The use of this segmentation model allows the definition of a strategy taking in consideration its aspects. In this subsection, we explain this strategy.

This latter is represented by algorithm called: Sensors Localization Algorithm (SLA) (Algorithm 1). This algorithm allows the assignment of sensors according to each segment. We can summarize the work method of this algorithm into the following points:

The distance between two successive sensors, changes according the RF of segment. Starting to that, first for the green road classes, we have placed the sensors in the way sequential linear the ones after the others on the border of the road. Second, for the orange road classes, we have also done the same way used in the green road classes. Except that, the difference between these classes, that we have added sensors on right border of roads. This operation is done through the following function: each time, after two emplacements of two successive sensors we put into middle of the distance which spares the second sensor and the following sensor on the left border of road a sensor on the right border of road. We have through to this operation because these roads types represent middle danger roads where the drivers need more roads information. Finally, for the red road classes, we have followed the same concept that the orange road classes except, we put a sensor on right border of road after one emplacement of a sensor because this class represents a high danger on the drivers. The sensors numbers in a segment segi (S number (segi)) respectively for green class, orange class, and red class according to our algorithm is defined into (3).

$$\begin{cases} S_{number}(seg_i) = SL \div (RF_i \times r) \\ S_{number}(seg_i) = S_{number}(seg_i) + 0.5 \times S_{number}(seg_i) \quad (3) \\ S_{number}(seg_i) = 2 \times S_{number}(seg_i) \end{cases}$$

Note: in orange class if Sensors number (segi) is impair number than we take absolute value of Sensors number (segi).

C. Topology and Architecture of Wireless Sensors Networks

The reparation of sensors in clusters represents an important aspect in WSN because it allows energy economy of sensors and makes the routing operation in WSN more easily. Each cluster is represented by cluster head (CH) and cluster members. The CH aims to make the coordination between its cluster members and it has the tasks of communication with the extern environment (others CHs and Road side unit (RSU)).In other hand, the cluster members communicate only between them and with their CH. According to our situation we have three cases (Fig. 1).

For segment of green class, we create cluster where the CH on the segment represents the last sensor which locates on the segment begging and the others sensors which locate on this segments represent the cluster members (Fig. 1. (a)). For segment of orange, we create the cluster like segment of green class except we add to each cluster the sensors which locate on the right borders of segment (Fig. 1. (b)). For segment of red class, we create two clusters (Fig. 1. (c)). The emplacements of the two clusters heads on beginning and ending of segment allowing to the drivers be informed of two sides of segment however the moving direction of the vehicle on this segment .

Algorithm 1 Sensors Localization Algorithm

```
Begin
for  i =1  to  Segment number (Ai) do
 for each road Ri  do
  Colour = Recupreate_Colour (Ri);
  if (Colour = green) then
   Put_Sensors (Ri, Green, Sk);
 else
   if (Colour = orange) then
    Put_Sensors (RS (Ri), Orange, Sk);
   else
     Put_Sensors ( RS (Ri), Red, Sk);
    end if
   end if
  end for
 end for
end
```

Procedures:

Put _Sensors (Ri, Green)

```
begin
 Position = r /2 ;
 for  j =1  to  Segment number (Ri) do
  while (Position ≤ SLj)  do
     Locate-sensor-in (Position, Sensor);
     Position = Position + (RFj × r);
  end while
  Position = r /2;
 end for
End
```

Put _Sensors (Ri, Orange)

```
begin
 Position = r /2 ;
 for  j =1  to  Segment number (Ri) do
 Cp = 0;
  while (Position ≤ SLj)  do
     Locate-sensor-in (Position, Sensor);
     Position = Position + (RFj × r);
     Cp++ ;
     if (Cp = 2) then
        Locate-sensor-in(Position + RFj × r / 2, Sensor);
        Cp = 0;
    end while
    Position = r /2;
  end for
End
```

Put_Sensors (Ri, Red)

The same procedure of orange road class is used in red road class except in this procedure we change if (Cp = 2) then by if (Cp =1) then

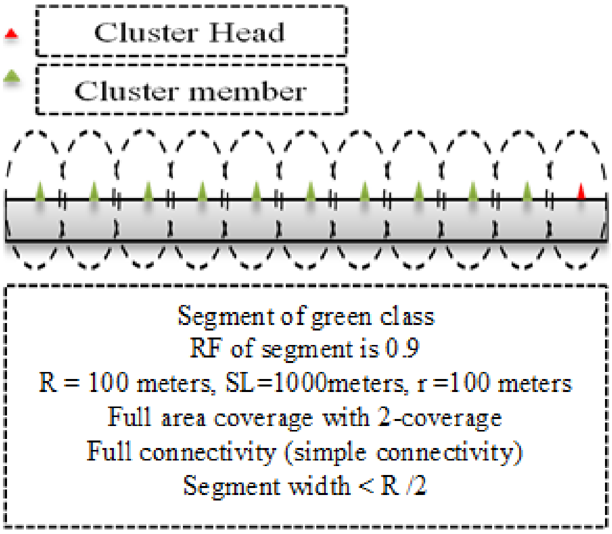

Fig. 1. (a) Example of Segment of Green Class in Urban Environment

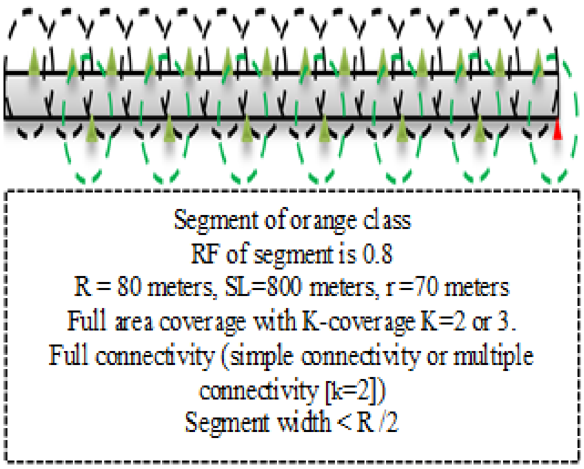

Fig. 1. (b) Example of Segment of Orange Class in Highways Environment

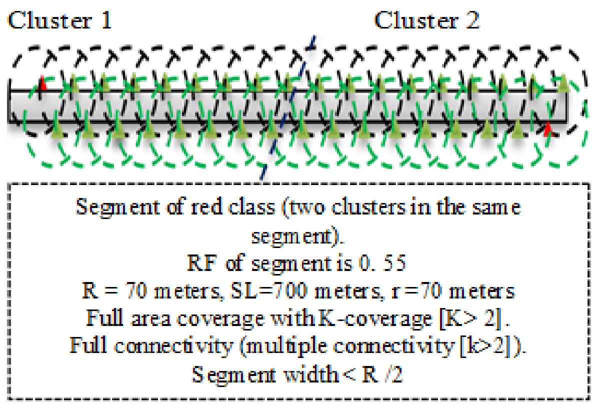

Fig. 1. (c) Example of segment of red class in rural environment Fig. 1. Exemple of clusters in the three classes

IV. RESULTS AND DISCUSSION

In this section, we present the results of our work while giving analyse of these results. To testing our proposition, we have used OMNet++ IDE 4.3.1 [8] simulator. We suppose that we have Ri road of 8 kilometres length and 15 meters of width (8000×15). This road is in a highways environment. We compare our deployment model with two types of uniform deployment models used on the same road. We suppose that in uniform model deployment type one, the distance between two sensors is r meters (maximal distance) and in the uniform deployment model type two, the distance between two sensors is r/2 meters (minimal distance). The Fig. 2 gives the number of required sensors in case of our proposition, and in the cases of the two types of deployment models road according to the sensing range r. In our proposition, we have used: (1), (2), and (3) respectively to calculate: the segment length (we suppose that the communication range of sensor R = 80m) (Table IV), the segments number, and sensors number. We have calculated the sensors number according to the three classes of roads.

Road Segments with Risk Factors

Segment	RF	Segment length (meters)
Segment 1	0.95	
Segment 2	0.93	
Segment 3	0.91	
Segment 4	0.9	
Segment 5	0.88	
Segment 6	0.89	
Segment 7	0.94	
Segment 8	0.86	800
Segment 9	0.9	
Segment 10	0.92	

From the Fig. 2, the numbers of required sensors in our proposition, change to a class to another class according to the present danger on road. In situation of the deployments models of the two types, these numbers change not, that proves the interest of our deployment which takes in consideration the geographic environment and road proprieties. The numbers of required sensors in our proposition, are not bigger than that into deployment model type two except the sensors number of red road, are bigger because this class represents a high danger class so we need more sensors to ensure an efficient monitoring.

For the coverage of WSN on the road, we note that, the results presented into the Fig. 3 prove that our proposition ensures more a coverage of road according to the sensing ranges of sensors than that into the deployment models of the two types. Besides, the coverage percent changes to a class to another class relative to the danger degree that is not the case in the uniform deployment models. We can justify these results because the localizations of sensors by class are matching with the road proprieties.

For the connectivity, we note that, the results presented into the Fig. 4 prove that our proposition ensures more connectivity of WSN according to the communication ranges of sensors than that into the deployment models of the two types. Besides, the connectivity of networks changes to a class to another class relative to the danger degree that is not the case in the uniform deployment models.

We can conclude that our proposition ensures a full coverage and a full connectivity. In green road, we have a simple coverage and simple connectivity. In the case of orange road and red road, we have multiples coverage and multiples connectivity. The percent of coverage and of connectivity in red road, are bigger than these on the orange road because the sensors number in these classes are not similar (the red class have a bigger number than that into orange class).

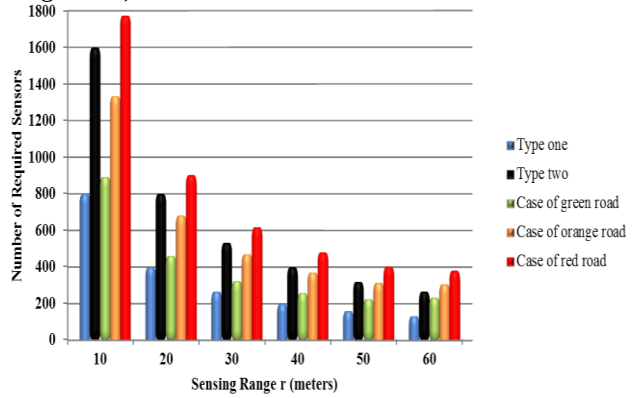

Fig. 2. Number of required sensors in the two deployment model types and our proposition in three classes according to the sensing rang r

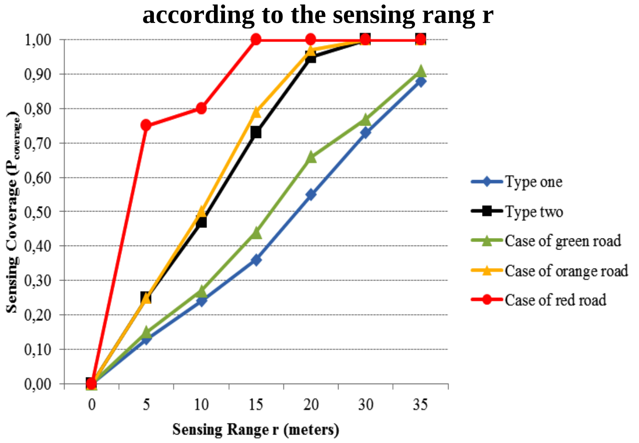

Fig. 3. Probability that any point in road is covered by at least one nearby sensor the two deployment models types and our proposition in three classes according to the sensing rang r

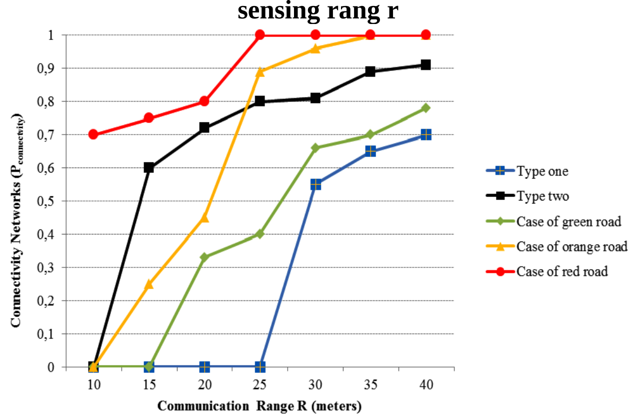

Fig. 4. Probability that WSN is connected into the two deployment models types and our proposition in three classes according to the communication rang R

V.CONCLUSION

In this article, we have presented our deployment model of WSN in framework of HSNV. This model is based on the geographic environment and the road proprieties. Starting to that, we have proposed a road classification which allows to us the creation of segmentation model. In this latter, we have decomposed the roads into a set of segments, in purpose to make the deployment operation of sensors on the roads networks more easily. We have also added a risk factor to each segment for approaching our deployment to the real environment. The sensors number and the distance between them, change according to these risk factors. Then, we have given our deployment algorithm called SLA which ensures full coverage and full connectivity of WSN. In addition, each time, the danger degree increases on the segment, the algorithm ensures a rate of coverage and connectivity bigger i.e. into the roads which represent a high danger on the drivers, we have multiples coverage and multiples connectivity. We have also, proposed a clustering way of WSN according to the class of the segment for economize the energy consumption of the sensors. As future works, we continue the improvement of our deployment model by the addition of others metrics liked to the sensors like the use of sensing ranges of sensors which are not similar.

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