Coordination Mechanisms for Floating Content in Realistic Vehicular Scenario

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***Abstract*—The increasing interest in vehicular communications draws attention to scalability and network congestion problems and therefore on techniques to offload the traffic, typically carried through the infrastructure, to the Vehicle-to-vehicle (V2V) network. Floating content (FC) represents a promising paradigm to share ephemeral content without direct support from infrastructure. It is based on constraining geographically within the Anchor Zone (AZ), the opportunistic replication of a given content among vehicles, in a way that strikes a balance between minimization of resource usage and content availability to users within the AZ. This paper constitutes a first attempt at addressing the issue of how to control FC performance in a realistic vehicular setting. It proposes a set of strategies for tuning the size of the AZ, based on the estimation of some key mobility parameters and of target FC performance.**

I. INTRODUCTION

Via Inter-Vehicle (V2V) and Vehicle-to-Infrastructure communications (V2I), drivers can be informed of road congestion, hazardous approaching vehicles and nearby advertisements. In some situation, infrastructure is not available and hence vehicles should rely solely on V2V communication to disseminate in a distributed way on-the-road information. It is worth mentioning that a significant amount of content exchanged between vehicles has the property of local relevance (time, space) [1]. The local relevance in space implies that the content has its own constrained geographically scope or area of utility to drivers. For instance, a shop advertisement is potentially relevant to drivers traveling nearby its location. On the other hand, the local relevance in time implies that the content must be available during a particular lifetime. In the case of a commercial advertisement, the content should be replicated among vehicles during the period of the special offer. While research community grappled with the dilemma of content availability to users within the region of relevance and minimization of resources usage (e.g., bandwidth, spectrum) in Mobile Ad-hoc Networks (MANETs) [2], [3], this dilemma is more complex and challenging in Vehicular Ad-hoc Networks (VANETs). Unlike MANETs, vehicular networks suffer from the volatility of inter-vehicular links and highly dynamic traffic conditions [4]. Furthermore, the VANET environment exhibits dynamic vehicle density from time to time and from one area to another. Such specular features hamper the efficient spreading of the content and accelerate the vanishing of the disseminated content by a seeder vehicle.

Recently, Floating Content (FC) has been proposed to efficiently facilitate the sharing of ephemeral content without direct support from infrastructure. It is particularly suited for applications for which the information is of common interest to all users within a given location called Anchor Zone (AZ). More specifically, the node possessing the content defines a circular area containing the node itself. Such seeder replicates the content every time he encounters a node without the content in its transmission range and within the validity radius. Nodes leaving the AZ consider the content as obsolete and hence discard their copy. Consequently, the content only persists in the AZ over time even when the seeder node has left the AZ. The operation of FC is illustrated in Figure 1.

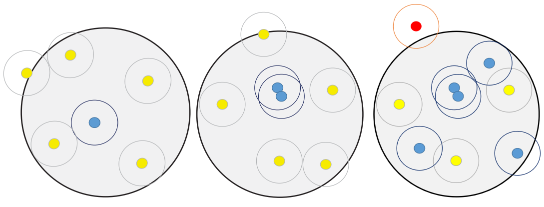

(a) (b) (c)

Fig. 1: Basic operation of Floating Content. 1a) Seeder (blue) defines the AZ. 1b) Opportunistic message exchange between nodes. 1c) Node going out of the AZ (red) discards the content.

FC has been studied mainly analytically. For instance, in [5], [6], authors investigated the criticality condition under which the content still available infinitely in the AZ. They concluded that the node encounter rate in the AZ and the node arrival rate are the key factors. However, infinite availability in the AZ does not necessary imply that majority of nodes got the content. To this end, authors of [7] provided an approximate analytical model that correlates between main parameters of FC (AZ radius, node transmission range and the average node density). Their model computes the *success probability*, i.e., the probability that a node entering the AZ gets the content before exiting, for different mobility models.

Aiming to address practical issues related to content availability in real environment with real propagation features, mobility patterns and communication protocols, authors of [8] investigated FC in an office setting environment. In this regard too, the work carried out in [9] has thoroughly assessed the performance of FC in a larger scale environment. Results show that, although a low node density and limited contacts frequency, content items persist over time within the AZ. Thus, authors proposed a simplified analytical model for computing the success probability.

However, the issue of how to use these results to dimension an FC service in a realistic vehicular setup is still open. The key problem is how to set up the FC parameters (AZ radius) to guarantee a minimum target performance level (content availability or probability of success) while minimizing the use of resources in the VANET. The dimensioning of AZ requires techniques for estimating the main parameters related to vehicles mobility in a region of space in the vicinity of the AZ center. So far, the issue of how seeders estimate such mobility features in a realistic setting, and of how to set up the AZ by taking into account the uncertainty in the estimation have never been addressed, despite its being crucial for the viability of FC. In this paper, we take a first step in addressing this issue. We consider in particular the model proposed in [10], based on mapping the mobility features to a random waypoint mobility model. We propose a set of algorithms for FC dimensioning based on estimation of some key parameters of vehicles distribution and mobility patterns. We individuate three algorithms with various degrees of infrastructure support in the form of (centralized or distributed) coordination mechanisms between nodes.

The rest of the paper is organized as follows: In section II, the system model is presented, introducing the estimation parameters to assess the performance of FC and stating the problem formally. Section III explains the dependencies between the success probability, AZ radius, and mobility features. Then, the algorithms to estimate the mobility characteristics either in a centralized or distributed way are presented, and their performance is assessed respectively in Section IV and V. Section VI concludes the paper.

II. SYSTEM MODEL AND PROBLEM FORMULATION

We consider an area, in which at any point in time we have a set of wireless nodes. By the term node, in this paper, we indicate a vehicle with a transmission range r. We assume two nodes come in contact when the distance between each other is $\leq r$. This model can be easily generalized to a more complex communication model taking into account fading, path loss and so on. Moreover, we assume that r is fixed for all nodes. In general, each node alternates between time intervals spent moving, and time intervals spent still. With term stopping time, we do not consider only when a node has zero speed but also when it covers partially the same area for a while (e.g. for vehicles, at a crossroad, or in a parking lot). The duration of moving time T_m and stopping time T_s are assumed to be independent random variables with pdf f_{T_m} and f_{T_s}, respectively. With v we indicate the mean average speed of nodes during a moving time.

We assume that at time $t = 0$, a node in the plane (the *seeder*) defines a circular area of radius R, the AZ, containing the node itself. Such seeder generates the content. For $t \geq 0$, every time a node with the content comes in contact with a node without it within the AZ, the message is replicated. We assume that nodes entering the AZ do not possess a copy of the message and those exiting (with a probability $1 - p$) the AZ, discard their copy of the content.

A first performance parameter of FC is content *availability* at a given time, i.e. the ratio between the number of nodes with content over the total amount of nodes inside the AZ at that time. The *success rate* in a given time interval, is instead the fraction of those nodes which left the AZ over that interval with a copy of the content, also called *success probability*. The optimization problem that we study in this paper is the determination of the optimal AZ radius that guarantees a given Success Porbability. Let us consider $R \in [R_{min}, R_{max}]$ as AZ radius, R_{min} as the minimum AZ radius required, R_{max} is the maximum AZ radius, P_{succ} as success probability, and P^*_{succ} as target success probability. The optimal value of R, called R^*, is given by:

$$\begin{aligned} &\textbf{minimize} \quad R \\ &\textbf{subject to} \quad P_{succ} \geq P^*_{succ},\, R \in (R_{min}, R_{max}) \end{aligned} \tag{1}$$

III. AN ANALYTICAL MODEL FOR SUCCESS PROBABILITY

In this section, we present the result which relates the success probability to the main system parameters.

We assume that the node mobility is such that node distribution in the plane at any time instant can be modeled as a Poisson point Process (PPP) with intensity λ. Examples of mobility models with such features are Random Direction (RD) and to some extent Random WayPoint (RWP). Although this last induces a spatial node distribution which deviates from a uniform distribution, authors in [11], introduce some bounds in which this assumption can be accepted.

We call *epoch* the mean time interval composed by a moving time and the subsequent stopping time on the path of a node (i.e. $T_{epoch} = E[T_m] + E[T_s]$). Therefore, a node sojourn within the AZ is a set of epochs. The following results assume there exists a *stationary state* in which the mean number of nodes with content within the AZ does not change over time. For a FC system in stationary state, we consider the probability for a node to get out of the AZ with a copy of the floating content, i.e. on FC *success probability*, as a measure of the the mean success rate.

If we consider λ as process intensity (i.e. arrival rate into AZ), the mean number of nodes in the AZ is $\bar{N} = D\pi R^2$ where D is the number of node for square metre. When $R >> r$, the mean number of nodes in AZ with (resp. without) content are given by [10]

$$\overline{n} = \bar{N} - \frac{1}{T_{soj}\nu Q} \quad , \tag{2}$$

$$\overline{m} = \frac{1}{T_{soj}\nu Q} \quad , \tag{3}$$

with T_{soj} as the mean sojourn time in the AZ, given by

$$T_{soj} = \frac{R^2}{rvq} \quad , \tag{4}$$

with $q = \frac{E[T_m]}{T_{epoch}}$, Q as the probability of success content transfer (in this paper we consider $Q = 1$) and ν mean contact rate between the two node.

Theorem 1 (Success probability)**.** *In stationary regime, if* $\overline{N} * T_{soj} * \nu > 1$*, the probability that a node gets the content during its sojourn time in the AZ is*

$$P_{succ} = \frac{P_{epoch}}{1 - p(1 - P_{epoch})} \tag{5}$$

where P_{epoch} *is the probability that a node gets the content during an epoch (other than the final one), given by*

$$P_{epoch} = P_m + (1 - P_m)P_s \tag{6}$$

P_s *is the probability of getting the content during a stopping time, given by*

$$P_s = \int_0^{+\infty} \left(1 - e^{-\nu\tau\bar{n}Q}\right) f_{T_s}(\tau) d\tau \tag{7}$$

with $f_{T_s}(\tau) = \frac{1}{\mu} e^{-\frac{\tau}{\mu}}$ *stopping time pdf.*
P_m *is the probability of getting the content during a moving time, given by*

$$P_m = \int_0^{\frac{2R}{v}} \left(1 - e^{-\nu\tau\bar{n}Q}\right) f_{T_m}(\tau) d\tau \quad . \tag{8}$$

Where the moving time pdf f_{T_m} *is given by:*

$$f_{T_m}(\tau) = \frac{4\tau v^2}{\pi R^2}\left(\arccos\frac{\tau v}{2R} - \frac{\tau v}{2R}\sqrt{1 - \left(\frac{\tau v}{2R}\right)^2}\right).$$

The mean contact rate between the two nodes is given by

$$\nu = \frac{2rqv(2(1-q) + 1.27q)}{\pi R^2}$$

q *is the mean moving time during an epoch, expressed as a fraction of the mean epoch duration, while* p *is given by:*

$$p = \frac{T_{epoch} + 2T_{soj} - \sqrt{T_{epoch}(T_{epoch} + 4T_{soj})}}{2T_{soj}} \tag{9}$$

For more the proof of Theorem 1, please refer to [10].

Note that the epoch in which the node moves out of the AZ coincides with the time spent moving towards the border of the AZ, as the node is assumed to disappear once reached the border. Hence for the final epoch $P_{epoch} = P_m$. Though being derived under strong assumptions on node mobility and spatial distribution, such result has shown to be in good accordance with empirical FC performance in a number of setups in an urban district, under very different mobility conditions.

When a seeder has to set an AZ radius which allows achieving a given success probability, it makes use of the relationship between R and P_{succ} established by the aforementioned result, plus possibly some safety margin. To this end, the seeder node needs some a priori information, namely:

- Mean moving time $E[T_m]$, and mean pause time $\frac{1}{\mu}$. These are determined by the specific street grid of a given city, and they have been shown to vary very little across cities, across different districts of the same city, and over the day.
- Q, the probability of successful content transfer during a contact. This is typically a function of message size and environment. Here we assume content item to be "small enough" to be transferred all at once, and there are not path loss or other communication issues.
- Mean node speed v;
- Transmission range r;

The only parameter which cannot be known a priori (if not from past history, but we assume this is not the case) is node arrival rate λ in function of the AZ size, shape and location where it is placed. In order to derive R as a function of P_{succ} via numerical inversion 1, a seeder needs to estimate the mean vehicle density $\tilde{\lambda}$ over the AZ area. Hence the estimate $\tilde{\lambda}$ is generally a function of AZ center $\underline{x}$, but also of AZ radius. The node needs to estimate the function $R, \tilde{\lambda}(\underline{x})$, for R within a given range of values (where the upper bound is set by city diameter, and/or by distance which would made the time necessary to spread content up to AZ border too large with respect to application constraints). Then compute the minimum R which guarantees the desired success rate via a greedy search. However, under the assumption of uniform node density, $\tilde{\lambda}$ can be evaluated considering half of moving nodes on the AZ border ($\tilde{\lambda} = 2DRqv$).

IV. AZ RADIUS ESTIMATION ALGORITHMS

Here, we describe a set of strategies for dimensioning the AZ, based on the estimation of vehicle density distribution (i.e., the "density map" of the area). We will assess them numerically on mobility traces drawn from measured data, and draw first indications on their performance, in terms of resource requirements (e.g. mean rate of data exchanges), and of ratio between the target success probability and the achieved success rate.

We assume each vehicle knows exactly its position in space, e.g. using a GPS device and the complete map of the area. The principal mechanism by which a vehicle or an RSU can estimate the position of other vehicles, and hence local node density, is by sending periodic beacons as in the case of IEEE 802.11p or Wi-Fi. The strategies we consider are:

- **Centralized, formula based**: We assume RSUs cover the whole area so that they can estimate node density based only on measurments. Each node periodically sends a beacon to the infrastructure, with its spatial coordinates at that point in time. Whenever a seeder requires setting up an AZ in order to start floating a message, such centralized coordination function gives to the seeder the value of R which achieves the target success probability, computed as described in the previous section. R does not change for the whole content lifetime.

- **Centralized, adaptive**: The base station/RSU infrastructure can coordinate the transmission between vehicles, and hence the replication of the floating content within the area. Specifically, teh RSU is able to change on-the-fly the AZ radius. Then, the infrastructure starts with a value of R computed as in the previous point, but then increases or decreases it according to the measured success rate and availability (note that in a realistic setting success rate is not monotonically increasing function of R).
- **Distributed, formula based**: In those contexts where infrastructure is missing, estimates of node density have to be computed by vehicles, possibly in a cooperative way. One easy approach is to assume a uniform node density in the interest area. In this case by counting the contact rate of the future seeder (i.e. number of nodes that come into the area covers by the seeder πr^2) is possible to estimate a minimum λ in order to respect the critical condition before mentioned. Therefore, fixing the success probability, it is possible to extract the respective anchor zone radius R. On the other hand, if each node builds its density map for location (e.g. in terms of meter square), we can estimate λ in function of R.
  Strategies differ on what is exchanged every time two nodes come in contact:
  - Node positions collected directly (no relaying of information from other nodes); It can be very inaccurate.
  - Node positions collected directly and relayed from other nodes. It can be very bandwidth consuming.
  - The estimate of node density for one or more points in space and time, built by the two cars;
  - The density map for the whole area, as built by each vehicle.
- **Distributed, adaptive**: In this case, each node may estimate the optimal R based on the density map it has built and acts accordingly.

V. NUMERICAL ASSESSMENT

We assess the performances of our algorithms using 24 hours of mobility traces of LuST scenario [12]. The simulations are performed in the area around Luxembourg City Center ($49^o36'44.1"N \quad 6^o07'33.1"E$), over two anti-meridian time intervals with different features: the first from 4:00 to 6:00 (light traffic) and the second from 7:00 to 9:00 (heavy traffic). The simulated vehicles communicate using Bluetooth class 1. Therefore, a reasonable node transmission range $r = 100m$ has been fixed for every simulation instance. According to the mobility characteristics reported in [12], the vehicles' mean speed, stopping time and moving time have been respectively fixed on $v = 18m/s$, $T_{stop} = 15s$ and $T_{move} = 25s$. Therefore, the time quota a vehicle spends moving is $q = 62,5\%$. For both algorithms, the mean arrival rate $\tilde{\lambda}$ is required as input for the chosen mobility model.

A. Centralized mean arrival rate estimation

In this configuration, the infrastructure, e.g. through RSUs, can estimate the mean arrival rate to the AZ for a certain radius. The AZ radius ranges from $R = 100m$ to $R = 1000m$, with steps of $100m$ for each simulation run. In both light and heavy traffic intervals of the simulation, the mean arrival rate $\tilde{\lambda}$ has been computed per each radius, as Fig. 2 and Fig. 3 show.

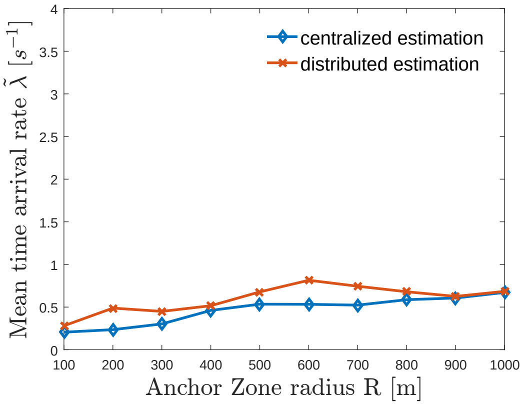


Fig. 2: Arrival rate 4:00-6:00 as a function of R

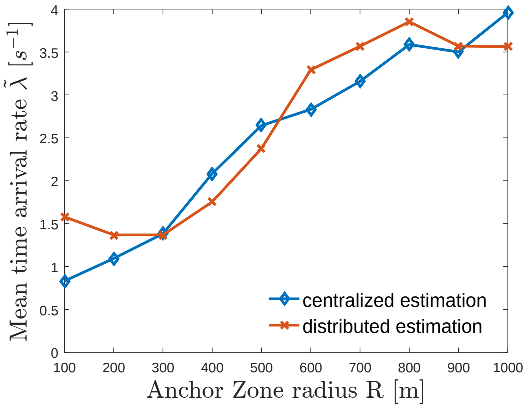


Fig. 3: Arrival rate 7:00-9:00 as a function of R

The couples $\tilde{\lambda}$ and the related AZ radius are input to the above-mentioned model, in order to obtain the estimated success probability for every simulated AZ radius. The results are reported in Fig. 4 and Fig. 5.

We can observe a general positive correlation between the AZ radius and the mean time arrival rate, but, due to the non-uniformity of the vehicle density, the trends do not show an increasing monotonic behavior. It is important to highlight that the algorithm that computes the arrival rate in the simulated environment ignores all the vehicles already inside the AZ and counts only the nodes that enter through its border. As reported in Figures 4 and 5, the values of the simulated success probability in both centralized and distributed ways, follow the

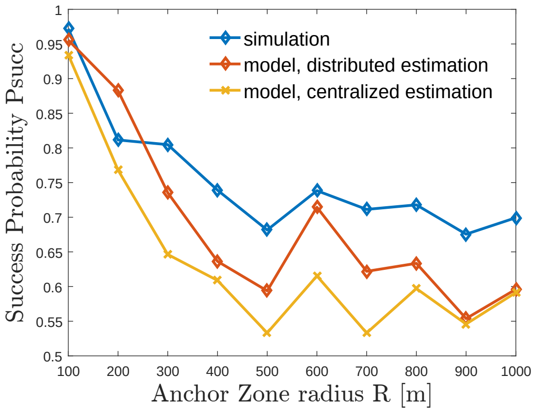


Fig. 4: Success probability 4:00-6:00 as a function of R

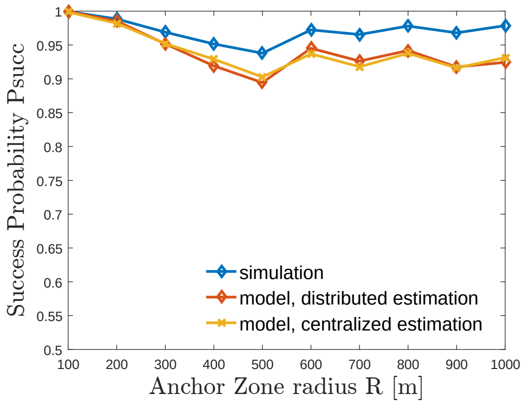


Fig. 5: Success probability 7:00-9:00 as a function of R

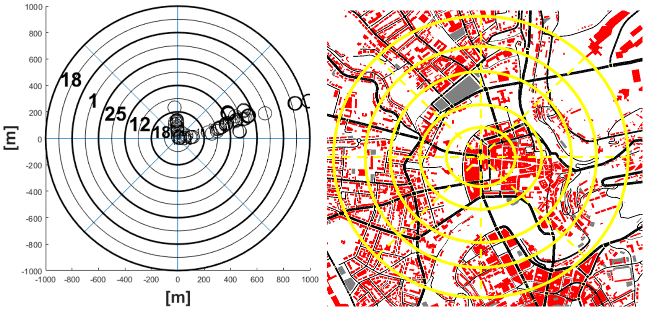
same decreasing trend as the success probability computed by the model, with a modest positive bias. For additional insights on how the centralized, formula-based approach works, please refer to Algorithm 1.

B. Distributed mean arrival rate estimation

In this configuration, there is no infrastructure support for the mean time arrival rate estimation. In order to simplify the estimation for a vehicle, we use a radial grid placed at the AZ center. Taking into account the whole set of AZ radius value and considering each 45^o of the grid, we obtain 80 sectors as Figure 6b shows. Each vehicle, during its sojourn within the AZ, gets in the range of other vehicles covering a subset of sectors. In each sector, has been estimated the number of vehicles in range and has been evaluated the respective mean node arrival rate for the consider value of R. Concluding, we consider a uniform node density, therefore, each sector, for the same AZ radius, has the same mean value. Figures 2 and 3 show the mean time arrival rate in the two range of time, while Figures 4 and 5 depict the P_{succ}. In Figure 6a, we see a general node contact path and the relative estimation of the mean time arrival rate. For additional insights on how the distributed, formula-based approach works, please refer to Algorithm 2.

Algorithm 1 Centralized algorithm, formula based

```
$V$ = ID set of all vehicles
$H$ = ID set of counted vehicles
$p(v)$ = GPS position of the vehicle
$p(AZ)$ = Center of the AZ
$R_{AZ}$ = Radius of the AZ
procedure CFB($V, R_{AZ}, p(AZ)$)
    $count \leftarrow 0,\ H \leftarrow \emptyset$
    for all $v \in V$ do
        if $\|p(v) - p(AZ)\|_2 < R_{AZ}$ then
            $H \leftarrow v$
        end if
    end for
    $T_{sim} \leftarrow 0$
    while $T_{sim} \leq 2h$ do
        for all $v \in V$ do
            if $\|p(v) - p(AZ)\|_2 < R_{AZ} \wedge v \notin H$ then
                $count = count + 1$
                $H \leftarrow v$
            end if
        end for
        $T_{sim} \leftarrow T_{new}$
    end while
    return $count/T_{sim}$
end procedure
```



(a)

(b)

Fig. 6: Generic node path within the radial grid. 6a) Node contact path and density estimation. 6a) Radial grid position above Luxembourg city.

C. Anchor Zone radius minimization Adaptive

Given all the mean time arrival rate estimations, we can perform our algorithm with the aim of finding the minimum R with respect of the conditions 1. The adaptive algorithm does not depend on the type of algorithm used to estimate the mean time arrival rate. Indeed, by distributed and centralized approaches, it is possible to extract the minimum value of R that respects conditions 1. Therefore, as Figures 4 and 5 show, the model is always conservative. The adaptive approach takes the value of R evaluated by one of the two approaches (i.e.

Algorithm 2 Distributed algorithm, formula based

```
$V$ = set of all ID vehicles
$p(v)$ = GPS position of the vehicle
$p(V)$ =set of all GPS vehicles position
$r$ = vehicle transmission range radius
$p(AZ)$ = Center of the AZ
$FR_{AZ}$ = set AZ Radius pairs    ▷ each element contains two consecutive AZ radius value forming a range
$F$ = set of arrival rate over AZ Radius
procedure DFB($V, FR_{AZ}, p(AZ), r$)
    for all $r_{az} \in FR_{AZ}$ do
        for all $v \in V \land p(v) \in r_{AZ}$ do    ▷ vehicle in range
            $count \leftarrow 0$
            if $\|p(v) - p(V)\|_2 < r$ then    ▷ element-wise
                $count = count + 1$
            end if
            $F \leftarrow EvaluateMean(F, count)$
        end for
        $F \leftarrow EvaluateFlow(F)$    ▷ by Little's Law
    end for
    return $F$
end procedure
```

Algorithm 3 Anchor Zone Radius Minimization Adaptive algorithm

```
$R_{min}$ = minimum AZ value required
$R^*$ = minimum AZ radius to achieve the Success probability desired
$P^*_{succ}$ = Success probability desired
$R_{max}$ = maximum Radius of the AZ
procedure AZRMA($R_{min}, P^*_{succ}, R_{max}$)
    $findit \leftarrow FALSE$
    while $R^* \geq R_{min} \land R^* \leq R_{AZ} \land findit = FALSE$ do
            ▷ given $R^*$ return the respective $P_{succ}$ of the model
        if $EstimatePsucc(R^*) > P^*_{succ}$ then
            $findit \leftarrow TRUE$
        end if
    end while
    if $findit = FALSE$ then
        $R^* = simulateRmax(R_{max}, P^*_{succ})$    ▷ given $R_{max}$ and $P^*_{succ}$ return $R^{'*} \leq R_{max}$ simulating $R_{max}$
    end if
    if $findit = TRUE$ then
        $R^* = simulateRfindit(R^*, P^*_{succ})$
            ▷ given $R^*$ and $P^*_{succ}$ return $R^{'*} \leq R^*$ sim $R^*$
    end if
    return $R^*$
end procedure
```

distributed and centralized) then measure the respective success probability in the real scenario decreasing progressively R. Finally, the algorithm converges to a lower value of R that still respect the condition 1.

VI. CONCLUSION

To overcome the short-lived intermittent connectivity and dynamic topology issues for content dissemination in VANETs, we rely on the new concept of Floating Content (FC) to make content items float within a constraining geographically area called the Anchor Zone (AZ). Tuning efficiently the parameters of FC is crucial to keep a balance between network resources usage and the probability of successful content delivery. In this paper, we formulate the problem of controlling the AZ radius as an optimization problem and propose an analytic model as well. Moreover, we propose three estimation algorithms with different degree of vehicular infrastructure support. Analytic model and algorithms are compared using the LuST real data set, and a good agreement is obtained.

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