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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. Existing works on FC performance modeling are based on standard, homogeneous synthetic mobility models, and it is hence unclear how they actually fit in realistic mobility scenarios. Moreover, the approaches to FC dimensioning they propose assume users have full knowledge of Spatio-temporal mobility patterns, which is hard to achieve in practice. Finally, despite FC is an infrastructure-less communication paradigm, some form of infrastructure support could be available in the vast majority of those application scenarios for which it has been proposed. In this paper, we perform a first attempt at tackling these issues. We focus on how to dimension an Anchor Zone in a realistic vehicular scenario. We propose the first set of simple dimensioning strategies, based on the estimation of some key mobility parameters and of FC performance. We assess such strategies on measurement-based vehicular traces, providing a first indication of their relative performance, and of the feasibility of FC in practical scenarios.**

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 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.

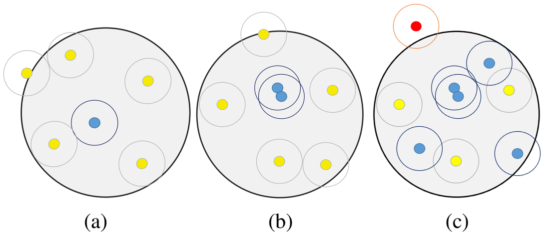

(a) (b) (c)

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. (Source: [6])

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 it encounters a node without the content in its transmission range and within the validity radius (i.e. Gilbert's model [5]). 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 Fig. 1. FC has been studied mainly analytically. For instance, in [7], [8], 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 [9] 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 patterns.

Aiming to address practical issues related to content availability in a real environment with real propagation features, mobility patterns and communication protocols, authors of [10] investigated FC in an office setting environment. In this regard too, the work carried out in [11] 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 [6], based on mapping the mobility features to a random waypoint mobility model. We propose a set of algorithms for FC dimensioning based on the estimation of some key parameters of vehicles distribution and mobility patterns. We individuate two 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

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 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 [11]. 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. It is an estimator of the *success probability*, i.e. of the probability for a node to get out of the AZ with a copy of the content [11], which we assume to be the ultimate goal of setting up a FC anchor zone for a content.

In vehicular scenarios, FC can be used to implement a variety of services and application. Examples are warnings on traffic jams or car accidents, in order to allow other vehicles to avoid getting stuck in traffic, and to mitigate traffic congestion in those areas. Whatever is the service relying on FC, we assume it comes with some minimum requirements on FC performance, in the form of minimum content floating lifetime, of maximum time required for a node entering the AZ to get the content, or in terms of minimum success probability. In what follows we assume the case in which the FC performance target is in terms of a lower bound P^*_{succ} to success probability. Moreover, as bandwidth is typically a scarce resource in vehicular ad-hoc scenario, any FC application must minimize the amount of resources required to achieve its target performance. In FC, this is achieved by minimizing the amount of content replications, and one of the ways to achieve this is by minimizing the amount of users which are required to replicate the content. In what follows we assume this is achieved by minimizing the AZ radius. In this case the problem of FC dimensioning consists in determining the minimum AZ radius which guarantees that the target minimum success probability is achieved.

Let us assume that the application imposes some form of lower bound R_{min} on the minimum AZ radius. In the case of a traffic jam, for instance, it makes no sense to have an AZ which is smaller than the area in which there is the traffic jam. Additionally, there is usually also an upper limit to AZ radius, typically dictated by common sense (e.g. no point to have an AZ so large that the time it takes the content to reach the border of the AZ is longer than the time interval within which the content is of some use to intended recipients). Let us consider the AZ radius $R \in [R_{min}, R_{max}]$, and let us denote with P_{succ} the success probability. The optimal value of R, denoted with R^*, is hence the solution of the following problem:

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

III. AN ANALYTICAL MODEL FOR SUCCESS PROBABILITY

In this section, we recall the main results, first derived in [6], which relate FC 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 uniform, with density D. Examples of mobility models with such features are Random Direction (RD) and, to some extent, Random WayPoint (RWP).

A. Analytical success probability for a circular AZ with RWP as mobility model

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. 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 [6]

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

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

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}*, according to RWP mobility model in a circular area 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:*

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

Please refer to [6] for the proof of Theorem 1.

Note that authors in [6], consider epochs as independent and identically distributed random variables. Therefore, by linear combination of P_{epoch} we obtain equation 5. Instead, P_{epoch} depends by the probability to get the content during moving time, and the probability to get the content during stopping time, equation 6. Both probabilities, i.e. P_m and P_s, are evaluated considering the amount of nodes entering in the area covered by the node during moving and stopping time. Then, by the law of total probability we obtain equations 7 and 8.

Moreover, 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 an urban district, under very different mobility conditions.

B. Model parametrization

When a seeder has to set an AZ radius to achieve a given success probability, it uses the relationship between R and P_{succ} established by the result mentioned above, 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 $E[T_s]$. 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.

- The probability of successful content transfer during a contact, Q. 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 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 make 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 ($\tilde{\lambda} = 2DRqv$) or simply by Little's law $\tilde{\lambda} = \frac{N}{T_{soj}}$.

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.

  For additional insights on how the centralized, formula-based approach works, please refer to Algorithm 1.
- **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.

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

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

Algorithm 2 Distributed algorithm, formula based

```
$V$ = set of all ID vehicles
$p(id_v)$ = GPS position of the vehicle
$p(V)$ =set of all GPS vehicles position
$r$ = vehicle transmission range radius
$x$ = Center of the AZ
$FR_{AZ}$ = set AZ Radius pairs          ▷ each element is a range
    composed by two consecutive AZ radius values
$\tilde{\Lambda}$ = set of arrival rate over AZ Radius     ▷ each element is the
    estimated $\tilde{\lambda}$ for the selected R
procedure DFB($V, FR_{AZ}, x, r$)
    for all $R_{az} \in FR_{AZ}$ do
        for all $id_v \in V \wedge p(id_v) \in R_{AZ}$ do   ▷ vehicle in range
            $count \leftarrow 0$
            if $\|p(id_v) - p(V)\|_2 < r$ then           ▷ element-wise
                $count = count + 1$
            end if
            $\tilde{\Lambda} \leftarrow EvaluateMean(\tilde{\Lambda}, count)$
        end for
        $\tilde{\Lambda} \leftarrow EvaluateFlow(\tilde{\Lambda})$              ▷ by Little's Law
    end for
    return $\tilde{\Lambda}$
end procedure
```

$r = 100m$ 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.

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 same decreasing trend as the success probability computed by the model, with a modest positive bias.

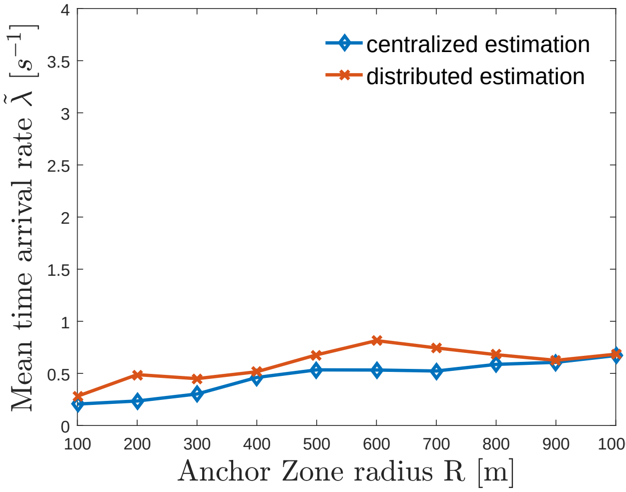


Fig. 2: Arrival rate 4:00-6:00 as a function of R

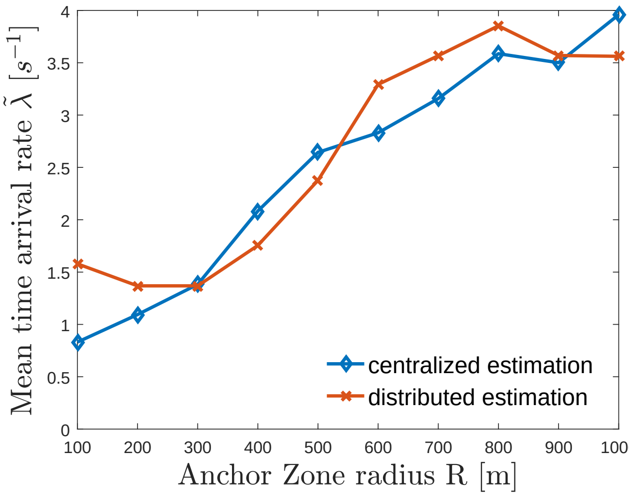


Fig. 3: Arrival rate 7:00-9:00 as a function of R

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.

It is important to notice that the overestimation of the distributed approach overcame the conservative approach of

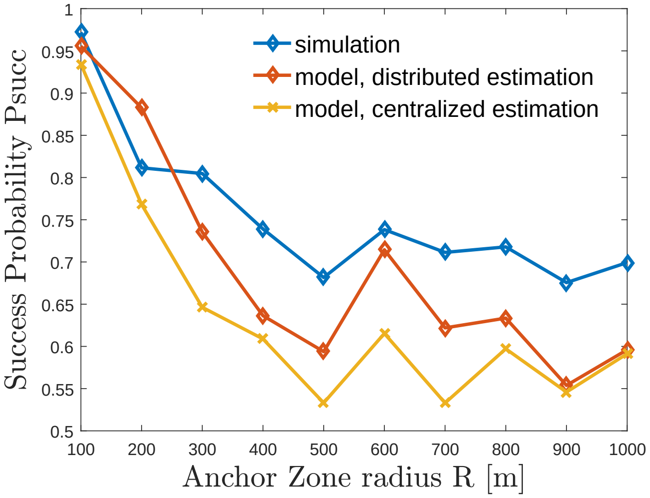


Fig. 4: Success probability 4:00-6:00 as a function of R

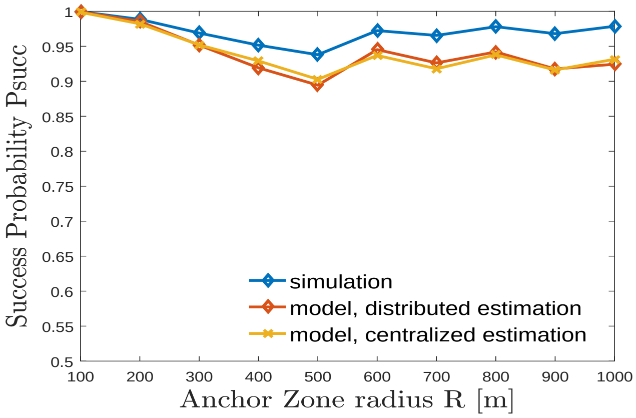
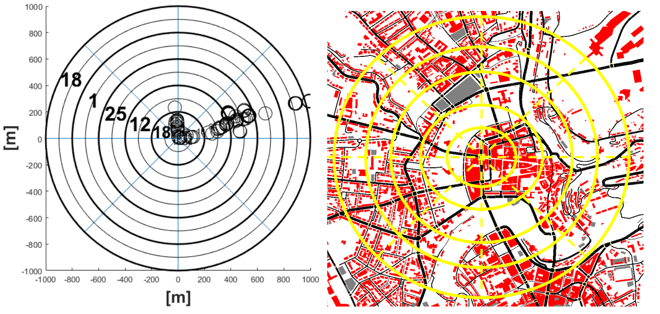


Fig. 5: Success probability 7:00-9:00 as a function of R

the model. In particular, we see that during low traffic time (i.e. 4:00-6:00), where the distributed estimation of the mean time arrival rate Fig. 2 involves a higher success probability. This reduce the distance between the distributed approach success probability and the simulation one Fig. 4.

VI. Conclusion

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 two 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. Counter-intuitively, increasing the value of AZ radius does not involve a success probability increases. Moreover, given the conservative approach by the model, the distributed algorithm, which does not require infrastructure supports, seems to perform better than the centralized one, in term of benefits costs. This last reasoning pushes to investigate deeper the distributed approach for future work.



(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.

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