Analysis of Vehicular Storage and Dissemination Services based on Floating Content

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Abstract. Floating Content is an attractive model for deploying and sharing information between mobile devices in a completely decentralized manner. For vehicular city-scale applications, the model has many applications. In this paper we conduct an analysis of the feasibility of such a model to support the sharing and dissemination of localized information, using realistic mobility traces in two different cities. As our experimental results reveal, the feasibility in urban environments is influenced by several factors. A high density inside the anchor location sustain the life of the information regardless the radius size. Having a big radius may cluster more vehicles and thus, increases the probability of floating. The radio range can also affect information sharing. A small radio range compared to the information availability range may prevent the application to spread content in the entire zone and rely on vehicle density. For all these, we provide experimental evidence.

Key words: Floating Content, collaborative sharing, vehicular networks, mobile data dissemination

1 Introduction

Mobile devices (i.e., smartphones, smart tablets, etc.) have become a staple of our society. Today, thanks to smartphone sensors and the possibility to combine their capabilities over advanced wireless technologies, information in the form of context becomes common input for applications running in our hand. Mobile applications can offer navigation in unfamilar places (e.g., Google Maps, Waze), or can socially connect people (i.e., Facebook, Twitter).

The evolution of location-aware mobile technology, in particular, has greatly influenced the mobile application industry. Facebook Messenger provides the users with the location of their communication partners. Its latest feature, Nearby Friends, sends notifications when the user comes within a short distance of a friend (if he chooses to share his location). Other location-aware applications tackle the increasing curiosity people have on others' activities (e.g., Tiner or Skout facilitate an interaction with nearby strangers).

Prior to the worldwide spread of smartphones, location was mainly used for space orientation. Applications such as Google Maps, Google Earth or Waze, can display information around the current position of the user. But, although mobiles devices have bigger storage sizes today, they are still limited when storing big amount of map data. Thus, navigators generally have to rely on the data network services to provide the user with detailed geographical views. However, recently navigation services have become social, and act as real communities where people share information with certain location importance. Maps support point-of-interest tagging, photo and text description, and even online street navigation. They are able to share information in real time.

Traditional social network applications (i.e., Facebook, LinkedIn) dependent on a centralized infrastructure to overcome distances and connect people located around the world. But a centralized infrastructure can introduce issues regarding content and location relevance and security [1]: (i) *location privacy* concerns (an application may need to provide the user with the exact location); (ii) *content privacy* issues (shared information can be stored by a private company, and be subject to censorship); (iii) *connectivity* to the infrastructure (can be a problem for traveling users who may have to deal with high roaming charges and unavailability of data services); (iv) *geographic validity* (locally relevant shared content may be of little interest to the rest of the world); (v) *temporal validity* concerns (shared content might be only valid for a limited amount of time); (vi) *user identification* (used to create some sense of responsibility towards the service provider, it can also raise a privacy issue since the shared information is associated with the owner, and companies can futher give access to their records to security agencies).

To respond to such problems, smart cities of tomorrow will probably rely on the use of a *content sharing service*, entirely dependent on mobile devices in the vicinity, and that will probabyl use principles of opportunistic networking [9]. Bringing social media and content sharing into ad-hoc networks seems the natural choice towards the next frontier in mobile industry [10].

The second context for the work being presented in this paper relates to *vehicle-to-vehicle wireless communication.* Research in advanced communication infrastructures at city-level has advanced today towards new applications for providing advanced levels of safety, entertainment and comfortable driving to a huge number of individuals that use vehicles on the roads every day [1]. Today car manufacturers introduce wireless communication equipment in their cars, and provide services designed to help drivers in case of accidents or collisions (e.g., Volvo introduced "Volvo on Call", and BMW their "BMW Assist" services). However, most implementations of such services rely on a centralized infrastructure. Naturally, the next step would be to modify the equipment in order to make use of inter-vehicle communication, a type of ad-hoc network which mainly uses broadcast as a method of information distribution [10]. The only limitations vehicles may have are the available transmission capacity which depends on the rate and the size of the information broadcasted.

The biggest challenge, still, with such solutions, is how to *make the information stay alive and "float"*, to achieve the main purpose of the sharing process which is to reach a high number of vehicles. In this paper we study the the feasibility of having such a distributed storage and dissemination service, addressed to overcome all the mentioned before problems.

We present an analysis of the floating content model to provide the innovative means to socially connect together participants within the city of tomorrow, and where storage and dissemination services on top of vehicular ad hoc networks will provide the means for AAL/ELE applications to connect together people and allow them to interact towards a common goal, such as for example monitor their well-beings, or discover in real-time vital location-based information such as accident in front, or the location of the nearby hospital.

The rest of the paper is organized as follows. First, we present the adaptation of a Floating Content model, towards a realistic vehicular mobility scenario. In Section 3 we present implementation details for this model, followed in 4 by experimental results. Finally, Section 5 presents conclusions and future work.

2 Floating Content

Our experiments are based on a model of sharing information originally proposed in [7]. Here, we extend this model with an analytical construct designed to describe the evolution of information over time, and add criticality conditions, adapted for the case of a vehicular ad hoc network. We consider a network that uses intermittent connectivity (a complete path cannot be established apriori to transmission from source to destination; vehicles can forward messages when they meet, one hop at a time, until the data eventually reach the destination) and forwarding mechanisms (to select the appropriate next hop, and avoid epidemic solutions because of possible congestion over the network) to facilitate communication.

2.1 Service model

We assume users to be mobile nodes who are interested in the content generated by other nodes. They use mobile devices able to handle the amount of data being exchanged during their participation in the ad-hoc network. Also, we assume a completely decentralized storage/dissemination infrastructure.

We assume nodes are uniformly distributed and travel independently, with a constant speed. We also assume mobile devices are equipped with wireless interfaces (Bluetooth or WLAN) to enable network communication. Analysis of performance for 802.11p standard displayed in [3] have shown that using a bitrate of 6 Mbps and a payload of 500 bytes yields a delivery rate of up to 80%. This indicates the acceptable reliability and performance of IEEE 802.11p, and confirms the viability of floating up to several megabytes of data (from 10 KB for text messages to 10 MB for photos). This standard is used also in our simulations, discussed further on. Making intuitive judgements, we can determine that contacts cannot last more than several tens of seconds, in vehicle case even less due to their high speeds.

The devices also need to be equipped with accurate systems to determine their position (e.g. using GPS tracking, cellular base stations, cell tower triangulations using WLAN access points or Wi-fi tracking). Many factors need to be considered, like accuracy needed, battery consumption etc. In order to provide the best location based service, the equipment must acquire the most accurate location coordinates. Finally, nodes need to synchronize their clock time so that users can process exchanged information (this can be done with the help of GPS or cellular networks).

2.2 System operation

As [7] presents, a node generates the information I, which has a size of $s(I)$ and a defined lifetime (Time to Live, or TTL, determining a validity period for the information, before it becomes obsolete). The information is tagged with the anchor zone, defined by its geo-located center P and two radii (see Figure 1): r identifies the *replication range*, inside which nodes replicate the information to other nodes they meet on their way, and a defines the *availability range* inside which the information is still stored with limited probability. These parameters are specific for each unit of information, and are defined by the creator of each particular message. Outside the availability zone there exist no copy of the item in the node data storage.

When two nodes meet in the anchor zone defined for a particular data, they share it. As such, all nodes inside the anchor zone should have a copy of the item (obtained while meeting other nodes already in the anchor zone), while nodes which are leaving the anchor can remove it at their own discretion. Let us consider two nodes A and B that meet. Node A does have an item I tagged with an anchor zone centered in point P and radii a and r. Let h be the distance of node A from the center P. When node A meets node B, item I gets replicated to B with the probability $p_r(h)$:

$$p_r(h) = \begin{cases} 1 & \text{if } h \leq r \\ R(h) & \text{if } r < h \leq a \\ 0 & \text{otherwise} \end{cases}$$

$R(h)$ is a decreasing function which determines the probability of replication between the outer replication border and the availability border of the anchor zone. The area between *replication range* and *availability range* acts as a buffer zone, that prevents immediate deletion of items. As shown in [7] and because of simplicity and more traceability, in our evaluation we assume no buffer zone.

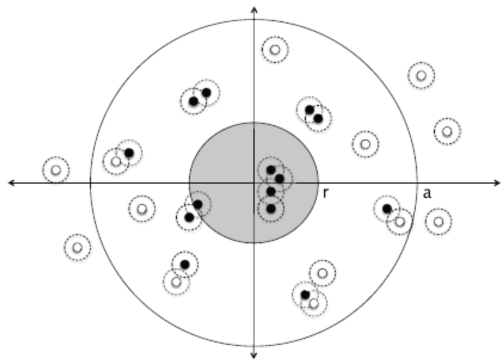


Fig. 1: Moving nodes inside an anchor zone. Black nodes are information-carrying nodes, white nodes will eventually get the information from the black ones. The probability of a node carrying an item tends to 1 inside the replication zone, and decreases until reaching an availability distance a after which no more copies are found (after [7]).

2.3 Analysis of the Floating Content model

The features of floating content offer exciting opportunities, but also introduces problems. The major challenge is that the communications service makes no guarantees that data will stay around until its lifetime expires. For example, during the night the content is expected to disappear. People's daily activities cause density fluctuations over the day, which may be a problem for the residing information in certain places. Thus, the information is expected to remain available for no more than a few hours.

Multiple use cases can emerge from the floating content concept. One of them can use infrastructure-less local data availability for advertising or selling goods. This type of market could have a dynamic catalog of available merchandise, being able to operate updates on the fly. Another one is information sharing between tourists and visitors about local attractions, or notifications about services a hotel is offering. Spreading news and keeping it localized, time-bounded and most important anonymous, can be another use case of floating content for which best-effort operation perfectly suits the needs.

Overall, floating content can be used in many ways, considering two important aspects of it. First, floating information is location-aware, so developers should consider multiple data-oriented architectures. The second aspect is that spreading the information while containing it to an anchor zone relies on a best effort approach, a problem which the Internet infrastructure solves with repair mechanisms that can recover lost packets. In Floating Content, data that expires becomes pretty much unrecoverable.

2.4 Analytical model

Similar to our paper, the Floating Content model has been a subject of analysis in [5]. The most important objective of this work has been finding a pattern to guarantee that a specific information remains in its anchor zone until the expiry of its lifetime with a high probability. It is called the *criticality condition*, and it depends on aspects such as mobility patterns and replication policies of the nodes inside the anchor zone.

While moving inside the anchor zone, a node may come in contact randomly with other nodes. We can assume there are two nodes moving permanently inside the zone. Let υ be the frequency at which they come in contact with each other. Assuming the population of nodes in anchor is N, the total number of pairs is $\frac{1}{2}N(N-1) \approx \frac{1}{2}N^2$ and the total rate of encounters is $\frac{1}{2}N^2\upsilon$. A part of these encounters, more exactly $2p(1-p)$, replicate an item to nodes that does not have it yet, thus the total rate of such events is $p(1-p)N^2\upsilon$. This rate shows the type of monotonicity of the size of the population which have the item I. Let $\frac{1}{\mu}$ be the time spent by a node in the anchor zone. It results that the total exit rate of nodes is $N\mu$, and the exit rate of tagged nodes is $Np\mu$. The growth rate is determined by the formula:

$$N\frac{d}{dt}p = N^2p(1-p)\upsilon - Np\mu \tag{1}$$

The two terms on the right are equal when in equilibrium, leading to the stationary value $p^* = 1 - \mu/(\upsilon N)$. In order to have a positive solution, $p^* > 0$, it requires that,

$$N\frac{\upsilon}{\mu} > 1. \tag{2}$$

Equation (2) is called *criticality condition*. The left side value represents the average number of collisions a randomly chosen node has during its sojourn time. Considering the sign of the equation (1), it can be seen that the solution is stable. When $p > 1-\mu/(\upsilon N)$, it tends to increase, and when $p < 1-\mu/(\upsilon N)$, it tends to decrease. The information disappears (even in the fluid model) when the derivative is negative, leading to the solution $p = 0$. Moreover, since we need to prevent accidental disappearance of the information carrying population by stochastic fluctuations, $Np = N - \mu/\upsilon$ must be large.

2.5 Information evolution during its lifetime

Inspired by the mathematical modeling of the spread of infection diseases [4], we decided next to extend further the analyze, by looking into the evolution of information spreading as if it was a virus. The reason we decided to perform analysis using this model is because the protocol proposed uses broadcasting as a way of transmission, known as epidemic routing.

Our approach is very similar with the SIR model [6]: S stands for susceptibles (nodes interested in information, which do not have a copy yet); I stands for the infected ones (nodes who have a copy, and can send it further to neighbours); R stand for the removed (nodes which deleted their copy of the message, either because their availability time expired, or they are out of the anchor range).

As shown in [4], we define r as the infection rate. The number of the infected is proportional with the current number of susceptibles and infected, or rSI. We define a as the removal rate. The number of removed is proportional to the infected nodes only, or aI. The number of each class can be, now, computed using the following conditions: $\frac{dS}{dt} = -rSI$, and $\frac{dI}{dt} = rSI - aI$, and $\frac{dR}{dt} = aI$.

These equations ensure that the total population $N = S + I + R$ and $S_0 > 0$, $I_0 > 0$ and $R_0 > 0$. Also, when a susceptible gets infected i.e. receives the message, it becomes immediately infectious.

From these equations, at the beginning of information exchanging, when $t = 0$ the following equation results:

$$\left.\frac{dI}{dt}\right|_{t=0} = I_0(rS_0 - a) \gtrless 0 \; if \; S_0 \gtrless \frac{a}{r} = \mu \tag{3}$$

There are two cases which emerge from (3): $S_0 < \mu$ implies that the number of infectives drop from I_0 to 0 and no epidemic can occur, $S_0 > \mu$ the number of infectives increases and the information spreads. μ can be considered as a threshold which determines whether the information will live or not. The presented model helps us to understand how the information develops in time, how the number of neighbours and the radius size influence its spread.

3 Floating Content Implementation

We decided to evaluate the conditions to use a Floating Content storage service within a city, by considering realistic vehicular mobility trace data. We used the Omnet++ network simulator, due to its extensibility and modularity. Also, we used the open-source framework for running vehicular network simulations called Veins, and Simulation of Urban Mobility (SUMO), a microscopic road traffic simulation package designed to handle large road network. Thus, we were able to perform bidirectionally-coupled simulation of road traffic and network traffic. Movement of nodes in Omnet++ simulation is determined by movement of vehicles in road traffic simulator SUMO. Nodes can then interact with the running road traffic simulation.

We assumed the use of the IEEE802.11p standard for vehicular communication. Also, to estimate the feasibility of floating content, we positioned anchor zones every 200m in a grid across the simulation area (which corresponds to a somewhat dense scenario for these zones). Every anchor zone had its own independent module to record multiple statistics during the simulation: the total number of vehicles crossing the anchor, the average sojourn time of a vehicle, the number of contacts of a vehicle during its sojourn time.

We simulated different scenarios using mobility datasets collected in San Francisco [8] and Beijing [11]. The territory of San Francisco, California covers an

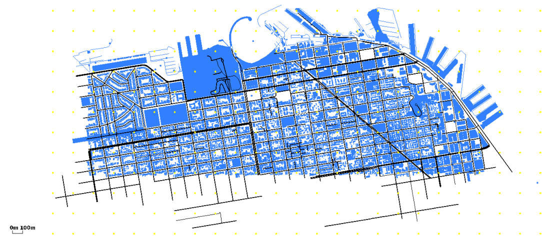


Fig. 2: Anchor zones every 200m over the simulation area.

area of about $121km^2$, whilst Beijing encompasses an area of about $16.807, 8km^2$. In case of Beijing, we slightly over 1000 cabs (corresponding to cars crossing our selected area), during one week (from 2nd February 2008, to 10th February 2008). For San Francisco, we simulated the movement of all 500 cabs in the datasets, over the period of 12 days (from 17th May 2008 to 29th May 2008).

In the end, we are interested in *criticality*, defined as the product between (i) the maximum number of nodes that exists at a given time in an anchor zone, (ii) the average number of contacts in during the sojourn time, and (iii) the average sojourn time of vehicles in an anchor zone.

The environment for our simulation required by Omnet++ was generated using OpenStreetMap [2]. We decided to use two different city scenarios (San-Francisco and Beijing) to show that floating content in urban environments is feasible regardless of particularity of road architecture (we have other results for different cities, such as Erlangen, but here we present only these 2 cities due to page limits). To analyse the model, we first vary the anchor zone radii, between $[200m, 500m]$. Although in theory IEEE 802.11p aims to provide both V2V and V2I communications in ranges up to $1000m$, due to obstacles and inferences we consider ranges between $[200m, 500m]$ to reflect more realistic somewhat-dense urban traffic conditions [3]. Figure 2 shows how anchor zones are distributed.

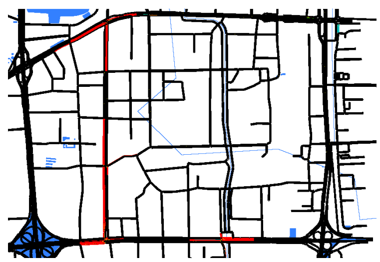
4 Experimental Results

We analyzed the feasibility of information sharing using the floating content model, considering the particularity of the road network as well as the spatial distribution of vehicles, and also the evolution during the simulation, following the SIR model.

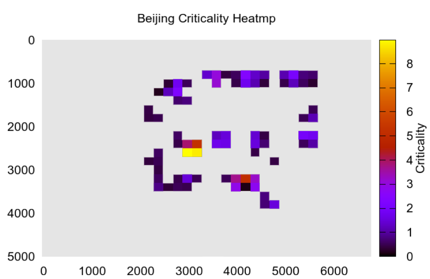
4.1 Beijing

Figure 3a displays an area within the Beijing city, where we conducted our simulations. The figure is a snapshot that displays the road network from an area of 6.7×5.2 km^2. The map is coloured with respect to the amount of time a car has to wait due to the traffic lights placed in intersections. Road segments coloured in red have a waiting time of about 40s, more than the ones coloured in black, where there is a continuous flow of vehicles (corresponding to a waiting time close to 0s).

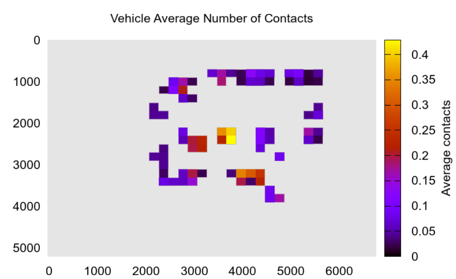
Figure 3b shows the *criticality* heatmap, and Figure 3c presents the average number of contacts a vehicle encounters during its sojourn time. The similarity between them is visible. The black (and gray, corresponding to value 0) areas state that the *criticality* factor is nearly 0, thus the probability of information floating is very low. Such areas occur in places between streets or outside the traffic road network, where neither vehicles, nor their radio range can reach them. In the 200m scenario, the anchor zones with a higher probability of floating scatter the map. In the blue coloured areas, results show an average *criticality condition*, slightly above 1, which corresponds to the criticality threshold. According to Figure 3c, 9 out of 10 vehicles do not have any interaction with other vehicles, during their sojourn time. The reason is the small amount of time spent in that location, and lack of neighbours at the time a beacon is sent out.



(a) Beijing traffic waiting time heatmap.



(b) Beijing Criticality Map $r = 200m$.

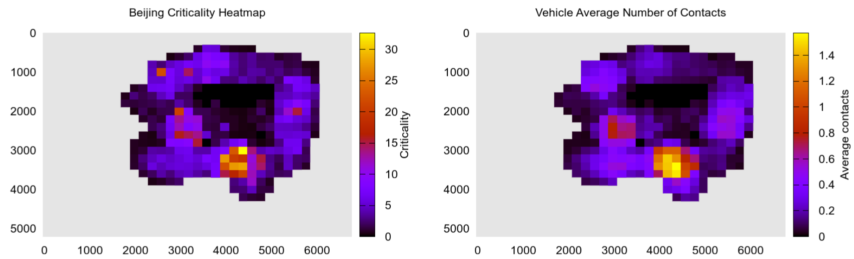


(c) Average Number of Contacts Map $r = 200m$.

Fig. 3: Beijing 300s simulation with 200m anchor size.

The bright yellow area, occurs naturally in the road intersection. The expectations for an information to live rise with respect to the average waiting time on a road segment. The *criticality factor* rise well over 8 as well as the average number of contacts a vehicles has during its sojourn time.

Increasing the anchor range yields better floating results. Figure 4 shows that information has a high probability of living along the road network. Also, the



(a) Beijing Criticality Map $r = 500m$. (b) Average Number of Contacts Map $r = 500m$.

Fig. 4: Beijing 300s simulation with 500m anchor size.

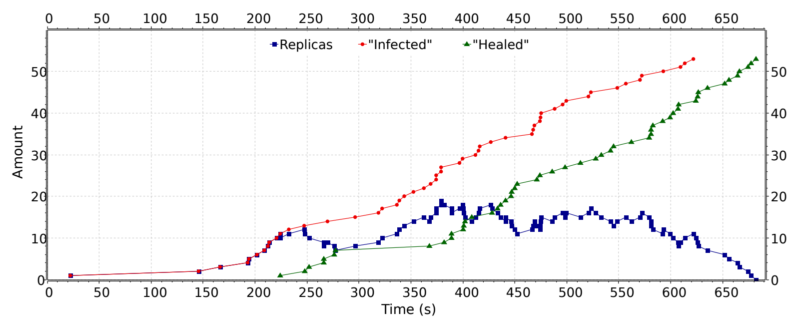


Fig. 5: Information life evolution with 500m range. The number of copies is equal with the total number of "infections" minus the total number of "healings".

small light yellow areas in figure 4b reflect that every node has at least one contact during its sojourn time. The *criticality condition* increases 4 times than the one computed for a range of 200m.

Figure 5 shows the information evolution within an anchor zone during a simulation time of 1000s: infected and healed. We decided to set the *ttl* parameter (time-to-live) to 600s, a realistic number that could be used for short lasting events and long enough to collect consistent data. We chose an anchor zone with a high number of information exchanges to provide a detailed picture of its evolution and avoided the ones which disappeared before the expiry time because of stochastic fluctuations.

We recorded the number of replicas an information has during the simulation denoted by *Replicas* label. The other two labels are 2 classes which belong to the epidemic SIR model: *infected* denote the information carrying nodes, and *healed* the ones which previously had a copy of the information and deleted it. The deletion could occur if the distance between the vehicle and the geo-location origin was bigger than the anchor radius or the information availability expired.

It is important to determine whether the information will spread or not. And if it does, for how long, and how it will develop in time. As we mentioned before, if $S_0 > S_c = a/r$ the content will spread. The plot in Figure 6

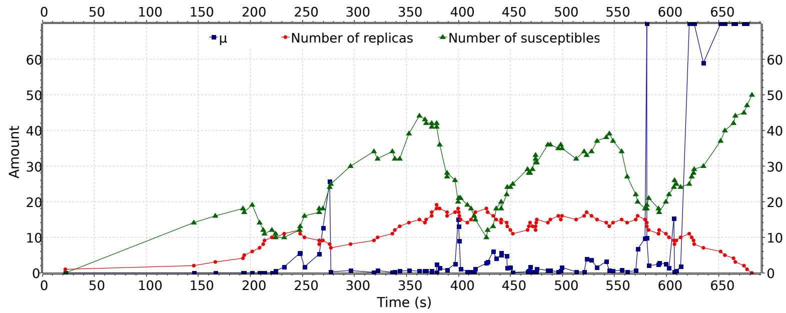


Fig. 6: When $S > \mu$ the number of replicas the number of replicas can increase, on the other hand, when $S < \mu$, the number of replicas decrease towards 0; μ represents the epidemy threshold; the anchor zone radius is 500m.

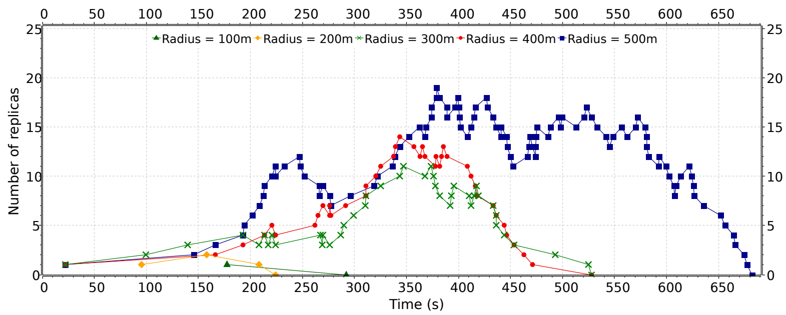


Fig. 7: Information life evolution with respect to radius size.

confirms the condition for a 500m anchor radius: the threshold μ is around 0 during most of the information lifetime, and the amount of susceptibles is greater than the threshold. This means that they could possibly receive a copy in the near future and become "infected". The end time period states that the number of susceptibles become less than μ, and thus the replication process reaches the end. The reason the threshold suddenly becomes larger is due to the application deleting the item once the lifetime expires. The "infected" will become susceptible again, fact confirmed by the figure (see the slight increase).

Figure 7 depicts how the information develops with respect to radius size. Establishing the optimum range enables the equipment and application to save battery energy and have a better resources management.

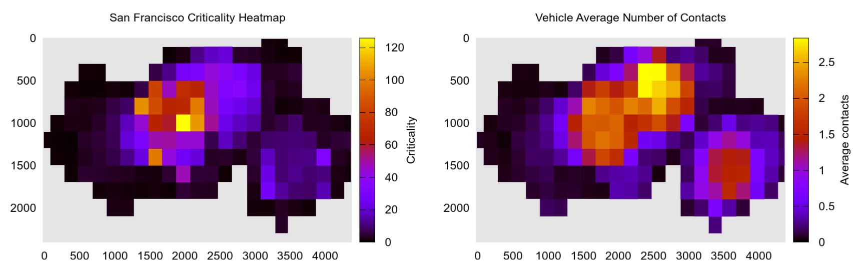
Anchor zones with $r \in [100m, 200m]$ yield a short life expectancy. In our scenario the content lasts for about 100s, just 1/6 of the due time. Such distances are probably more suitable if used indoor public places like shopping malls, metro stations, usually overcrowded places were the message exchanging is possible.

Ranges within $[300m, 400m]$ increase the life time up to 500s, but the information disappears ahead of time. The range of 500m keeps the item alive until its termination time. As long as the range is big enough to hold a considerable amount of vehicles inside, the information will last.

4.2 San Francisco

The area selected from San Francisco to be used in simulations has 4.5×2.5 km^2, and contains a road network made up from road streets with different numbers of lanes on each way. We removed the bicycle, pedestrian, cityrail and public transport segment roads, and left only the segments for regular road vehicles.

Figure 8 depicts the results using an anchor range of 500m. While the average number of contacts slightly increases from 2 to 2.5 the *criticality* reaches 120 in the top spots, nearly 2.5 times than the former approach. This is possible because the anchor zones now cover larger areas, thus involving more cars in the exchanging process. The bigger radius make the anchor zones more diffusive inside the heatmap confirming that a user may receive much more items spread on a larger area. In the 200m scenario, the areas are more concentrated, with the need of being close to the high traffic zones in order for the replication to be possible. The big values that appear over a big portion of the map are an indicator that even in the probabilistic system used the information will float.



(a) Criticality Map $r = 500m$.

(b) Average Number of Contacts Map $r = 500m$.

Fig. 8: San Francisco 300s simulation with 500m anchor size.

Again the epidemic model SIR is confirmed, as shown in Figure 9. During its lifetime the removal rate is close to 0. Around $t = 475s$ a spike occurs in the epidemic threshold μ which is a sign that vehicles deleted their copy of the item when got out of range. The number of susceptibles is above the threshold, so epidemy is sustained and the number of replicas stays around 70.

When lifetime expires, the replication rate drops to 0 and the deletion rate starts increasing. The threshold thus gets over the number of susceptibles. Same happens with the number of susceptibles, because the information carrying nodes start information deletion process and transform into susceptibles again. The anchor zone is crossed by a higher number of vehicles if we take a look at the number of susceptibles. Another indicator is the fact that the average number of replicas is much higher, with less than 20 in Beijing and over 70 in the current scenario.

Figure 10 describes how the spread develops in time with respect to anchor radius size. It indicates that when $r \in [300m,\ 500m]$, the information floats the

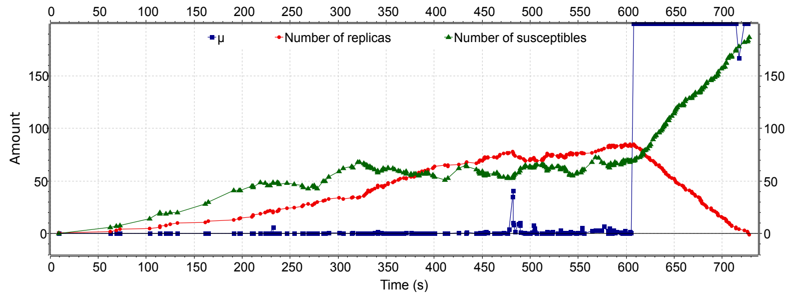


Fig. 9: When $S > \mu$ the number of replicas the number of replicas can increase, on the other hand, when $S < \mu$, the number of replicas decrease towards 0; μ represents the epidemy threshold; the anchor zone radius is 500m.

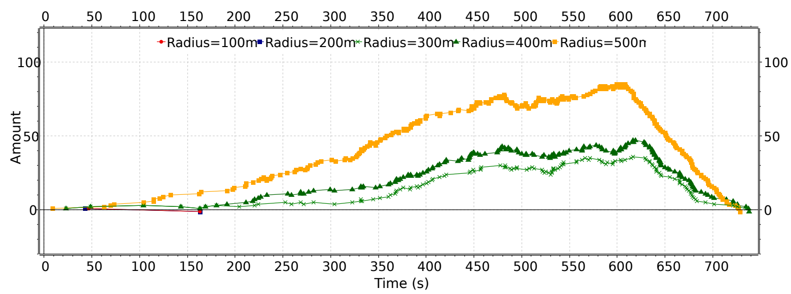


Fig. 10: Information life evolution with respect to radius size.

entire due time. Intuitively, the distinctive aspect is the average number of replicas proportionally with the range size. A lower radius kills the item prematurely, existing no peer to exchange messages with.

5 Conclusion

We have presented an analysis of distributed storage and dissemination services based on floating content design, that works exclusively on mobile devices without relying on a central infrastructure network. We performed our evaluations using realistic scenarios and the results revealed that floating content could be feasible in urban environments.

There are several important factors that influence information floatability. A high density inside the anchor location sustain the life of the information regardless the radius size (but the number of copies would be small for small radii). Having a big radius may cluster more vehicles and thus, increase the probability of floating. The radio range could also affect information sharing. A small radio range compared to the information availability range may prevent the application to spread content in the entire zone and rely on vehicle density.

We believe information sharing applications between mobile entities will experience a growth in the near future, a prediction supported by the improvements made in wireless communication, the increase spread of mobile phones worldwide, and the construction of vehicles with communication equipment.

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