Content Sharing in Pedestrian-based Micro Clouds

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***Abstract*—The continuous growth of the urban population and the high development and maintenance costs of infrastructure-based approaches make it necessary the utilization of distributed schemes. Among distributed systems, there is an increasing interest in edge cloud models, both for vehicular and pedestrian applications. In this paper, we developed a distributed application based on the micro cloud concept formulated in the field of vehicular edge computing for spreading content items in an indoor pedestrian environment. Results highlight how it is possible to reach both 100% content items spread and up to 66% reduction over channel collisions.**

***Index Terms*—Edge computing, micro cloud, pedestrian mobility, intelligent transportation systems**

I. Introduction

Faced with growing cost of infrastructure, distributed approaches for information dissemination and retrieval have the potential of turning the large demand into an advantage. Distributed systems applied to models of sharing economies can benefit from large user demands by spreading content items in wider areas. Nowadays, an increasing number of applications successfully implement sharing economy methods through gamification and app engagement techniques: the more users are willing to share content items with other users, the more rewards they may obtain in terms of price discounts or even cashback. Waze is an example of an app where users share information on online platforms and receive a reward proportional to the amount of items shared.

Much in the same vein, floating data is viewed as an excellent solution to spread information in distributed environments. In particular, micro cloud-based applications exploiting a sharing approach represent prime building blocks for the next generation of Intelligent Transport System (ITS), as detailed in the next section of literature review. This trend is embraced not only by vehicular communication models, but also by other kinds of hybrid mobility, including inter-pedestrian communication environments [1]–[3]. Mobility models are now available for selected scenarios and even allow first-edge computing approached in the presence of pedestrians [4], [5].

In this paper, we present a content sharing application suited for a pedestrian-based micro cloud environment. Our work improves the existing literature by several aspects, namely:

- by applying the micro cloud concept, widely used in a vehicular context, to a pedestrian environment;
- by proposing a content item sharing application with rewards suited to the proposed use case;
- by developing scenarios with and without data sharing, with data sharing and congestion control and by comparing them with a benchmark scenario.

The paper is organized as follows: Section II is dedicated to related works in literature, while Section III presents the use case we focused on for our application. In Section IV the methodology used for instantiating the content creation procedure and the content sharing methods are described. The same section also includes a description of the considered scenarios. Results are presented in Section V, while conclusions and future work are in Section VI.

II. Related Work

Multi-access edge computing [6]–[8] is one of the key network architecture concepts in 5G networks. The main idea is to bring computational, storage, and communication infrastructure closer to end users. As communication with back-end cloud services always comes with added network delay problems, having popular or frequently used data cached in the edge servers helps reducing latency [9]. Generally, edge-supported services can be classified as computational offloading, content delivery, aggregation, local connectivity, content scaling, and augmentation [10].

Performance gains from an edge computing architecture are possible only when edge servers are densely deployed. In [11], the authors found out that the location of deployed edge servers is very critical for supporting services, e.g., vehicle-to-everything services, which demand high link capacity.

The lack of edge computing infrastructure in the vicinity can be complemented by virtual edge servers [12]. The idea is to virtualize the physical edge computing infrastructure using on-board computational and storage resources of the cars, whose communication capabilities may be leveraged to form small clusters called *vehicular micro clouds*. These clusters can be formed based on parameters like driving direction, location, speed, etc [13], [14]. Vehicular micro clouds can then share their rich resource pool to provide edge computing services.

Recently, protocols designed for vehicular edge computing [15] have been adopted and studied for content dissemination via pedestrian mobility [5]. The authors in this paper use pedestrian mobility traces obtained using the ONE simulator [4] and focus on making content items available within certain geographic regions through pedestrians, optimizing for network and storage usage on mobile devices. In this paper, we follow the concepts of vehicular micro clouds to study content sharing via pedestrians using opportunistic communication in a subway station scenario generated in [16].

III. Case Study and System Description

The aim of the present work is to analyze the performance of a content sharing system in a distributed environment. In particular, we aim to reproduce an application for data exchange between pedestrians. The simplest way to represent such a model is by means of simulation with a realistic pedestrian mobility model input to the system. It is extremely difficult to retrieve online a pedestrian trace covering a wide area with a good level of realism. For this reason, the choice of the mobility environment usually affects the use case selection.

The mobility environment chosen for our scope was taken from [16], where the authors aimed to reproduce a realistic mobility scenario for evaluation of opportunistic wireless communication. In order to replicate an ad-hoc pedestrian network with a strong resemblance to reality, they calibrated and validated a mobility model by measuring and monitoring pedestrian behaviour, both in controlled settings and with real pedestrian crowds in a real environment. The final outcome is a complete set of synthetic mobility traces from a subway station in the Ostermalm area of Stockholm.

We believe that the selected use case perfectly suites the application we want to target. The coffee shop and the stores in the station main hall can conceivably represent the places where content is generated, in the form of advertisements and special offers on a mobile app. Users are then enticed to spread such information through the subway station by receiving a reward (cashback or discounts) proportional to the quantity of data shared with other users. Such an app can also be leveraged by the transportation authority so that passengers roaming the station can be used as a vehicle to disseminate useful information on train schedules and service disruptions. Such information can either be generated on the fly by users waiting for the train arrival on the platform area or, if information is previously known (e.g., trains being canceled due to planned strikes or line maintenance), it can be provided by the local transportation authority to shop owners for dissemination through the app. Data dissemination services can also be rewarded with special discounts on transportation ticket prices.

In view of the mechanism described above, we propose and evaluate a data dissemination application in a micro cloud distributed environment. Micro clouds are the optimum choice for floating data contexts that do not rely on infrastructure. Being infrastructure-independent significantly reduces costs, but it shifts the burden to the users. In particular, we assume that every user carries a smartphone that can perform indoor localization correctly (beside being an actively researched topic [17] [18], indoor localization is nowadays supported by most smartphones [19]) and, through the content sharing app, can recognize the micro cloud it is crossing.

The map of the subway station used in [16], as well as in our study, is depicted in Fig. 1, where green zones highlight micro cloud areas of interest. In particular, the micro cloud areas are the north corridor (m1), the west escalator (m2), the east escalator (m3), the entry hall (m4) and the platforms area (m5). Red regions represent walls hindering radio communication.

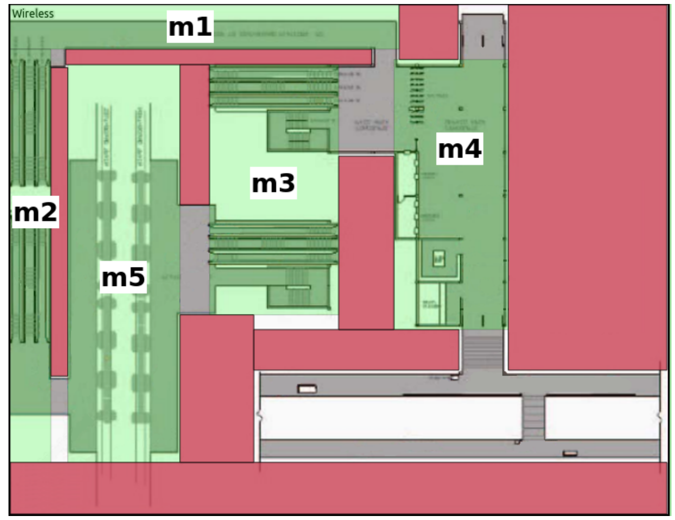


Fig. 1: Ostermalm subway station map with micro clouds.

Data is assumed to be exchanged through packets broadcasted via WiFi Direct. Packets can be of two kinds: beacons and data packets. Through beacons, sent at a frequency of 10 Hz, hosts can share basic information such as:

- Transmission timestamp;
- Host IP address;
- Host motion information: current host position, heading, speed and the current micro cloud the host is crossing (if any);
- List of owned items of data content;
- List of creation times of items of data content;
- List of missing items of data content.

Data packets are simple packets containing the data content ID, a random byte-stream sequence mimicking 2 KB worth of data content and its corresponding creation time.

Through beacons and their own localization, hosts can collect data from neighbors and are capable of recording motion and content details in basic data structures. In particular, every host leverages two internal data structures: the *Host Storage*, in charge of collecting motion data (i.e., timestamp, host IP, position, speed, heading, micro cloud) about itself and its neighbors and the *Content Manager*, collecting information regarding content owned by hosts (i.e., timestamp, host IP, micro cloud, owned data, creation times and missing data list).

IV. Content creation and sharing procedures

The model presented in this paper aims to reproduce a realistic indoor pedestrian mobility environment with the sharing of contextual information in a subway station when M micro clouds are present. Therefore, content items created in each scenario are supposed to be meaningful for the micro cloud they belongs to, e.g., an early/late train departure information will be linked to the platforms area, while the announcement of a new item in the store or in the coffee shop is an example of data content likely created in the main hall micro cloud. To model the creation of micro cloud-relevant content, a generation process was defined as follows: as soon as a host finds itself in a micro cloud, and as long as it remains there, it generates a piece of data content according to a Poisson process with a rate λ. The system allows for a total of N_c different content items, out of which up to $N_m = N_c/M$ can be associated with a single micro cloud. Every item has a limited lifetime of T_l, after which it is deleted from the host storage. Hosts inside a specific micro cloud can own every kind of content, but can only create content items for the micro cloud where they are transiting. As an example, hosts in the north corridor cannot have information on train delays in a direct way. Indeed, this information has to be shared by users coming from train platforms. Thus, no content on train delays can be generated outside the platforms. Multiple scenarios were analyzed in order to compare the performance of the model at different levels of complexity.

A. Baseline scenario

In the first scenario, used for benchmarking purposes, hosts are not allowed to share data content, thus only beacons and not data packets are exchanged. There, hosts only read broadcast beacons and they update their own Host Storage and Content Manager with neighbors' motion and content information. Upon a beacon reception, the receiving host looks up the list of advertised content items sent by the other host and inserts any content items that are missing from their own missing data list. As a consequence, in this baseline scenario, creating content is the only way to own a specific content item. The procedure adopted by hosts at this stage of the model is reported in Algorithm 1 from line 1 up to line 7.

Algorithm 1 Content sharing procedure.

Data: On beacon received
1: Update the Host Storage with sender's motion info
2: Update the Content Manager with sender's owned and missing data lists
3: **for** every item owned by the sender **do**
4:   **if** there is a content item missing by host **then**
5:     Add that item in host's missing list
6:   **end if**
7: **end for**
8: **for** every item in the sender's missing list **do**
9:   **if** there are items owned by the host **then**
10:     **if** host is entering in a new micro cloud **or** host is leaving the current one **then**
11:       Select the owned item with the longest remaining lifetime belonging to a micro cloud different from the current one
12:     **else**
13:       Select the owned item with the longest remaining lifetime belonging to the current micro cloud
14:     **end if**
15:   **end if**
16: **end for**
17: **if** there is a content item to send **then**
18:   **if** my collision rate is below C_r **then**
19:     Send the data packet
20:   **end if**
21: **end if**

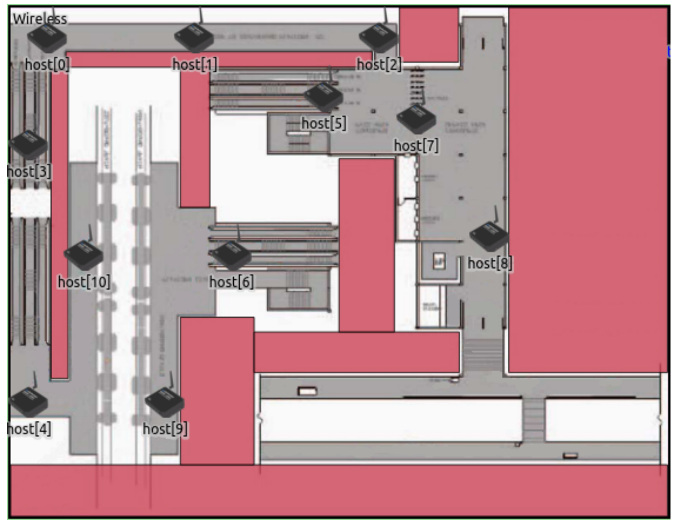


Fig. 2: Access Points locations in map environment.

B. Data sharing scenario

In a second scenario, hosts share content items via data packets. When a beacon is received with some items marked as missing by the sender, the recipient host checks whether it owns them or not. If so, the item with the most recent creation time is chosen, i.e., the one that has the longest remaining lifetime. The selected item will be broadcast encapsulated in a data packet and will be received by all the sender's neighbors. Hosts correctly receive these data packets and add them to their Content Manager. The procedure described in this subsection is reported in Algorithm 1, except for lines 10 to 14 and without the "if" condition on line 18.

C. Data sharing scenario with congestion control

The purpose of the third scenario is to reduce the number of channel collisions. To this end, unlike the second scenario, content items are broadcast only if the rate of collisions on the channel detected by the host is below a given threshold C_r. Furthermore, in this scenario, a procedure for spreading content items through different micro clouds is introduced. Based on its own motion information, when a host has just entered or is about to exit a micro cloud region, it is allowed to share only data belonging to other micro clouds. Conversely, if motion data suggests that the host is lingering in the same micro cloud region, the host is forced to share content items belonging to the current micro cloud. In such a way, the sharing of content throughout different regions of the map

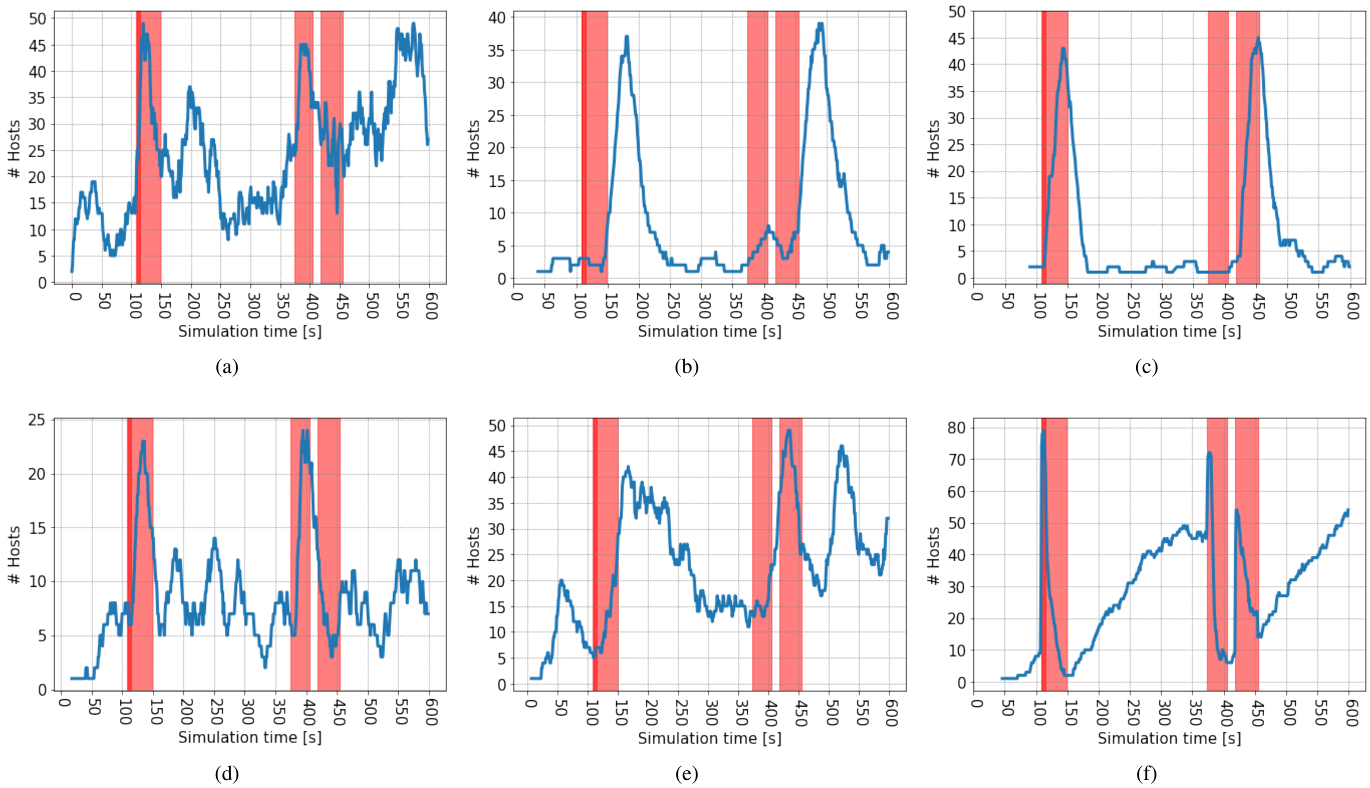


Fig. 3: Number of hosts throughout simulation for every micro cloud area. Red bars represent train arrivals. (a) Hosts outside micro clouds. (b) Hosts in the north corridor. (c) Hosts in the west escalator. (d) Hosts in the east escalator. (e) Hosts in the main hall. (f) Hosts in the platforms area.

is promoted. The complete Algorithm 1 represents the whole procedure at this stage of the model.

D. Access Points benchmark scenario

Eventually, a benchmark scenario with Access Points (APs) is also analyzed. In this scenario, 11 APs were located in fixed positions on the map , each one in radio visibility of one or more other APs. The resulting model is depicted in Fig. 2. In this scenario, APs are the only ones entitled to create and broadcast content items, while hosts can only share motion information through their beacons. This last scenario represents an infrastructure-based model, where items are managed by a few entities (i.e., the APs) with a different sharing model than the hosts. This scenario has been developed as a benchmark model, where better performance is offset by high equipment costs.

V. Results

The simulation environment used for this project is the INET Framework [20], an open-source communication network simulation package, written for the OMNeT++ [21] simulation system. The INET model used as a baseline is a UDP basic application. Hosts can move following a motion model and can exchange basic UDP packets, leveraging WiFi Direct communications. Starting from this, a BonnMotion [22] model of mobility traces from [16] was created and introduced in the simulator. The radio channel was modeled using the “APSK scalar radio medium” INET package, with yields ideal obstacle loss and simple path loss models with 50 m communication range and 90% of packets received at a distance of 40 m, mimicking an indoor WiFi communication environment using APSK modulation.

Hosts were also supplemented with energy storage and consumption models with a 3.1 Ah maximum capacity (i.e., a good-quality battery capacity for a smartphone). A random energy level from 0% to 5% was assigned to every node at the beginning of the simulation. In this way, we were able to deal with sudden deactivation of hosts due to poor battery levels.

TABLE I: Simulation parameters.

Description	**Value**
Simulation time limit	600 s
Number of micro clouds M	5
Total number of content items N_c	50
Content item lifetime T_l	50 s
Content item size	2 KB
Beacon frequency	10 Hz
Content items generation rate λ	0.2 s^{-1}
Channel collision threshold C_r	100 collisions/s
Host transmission bit-rate	1 Mbps

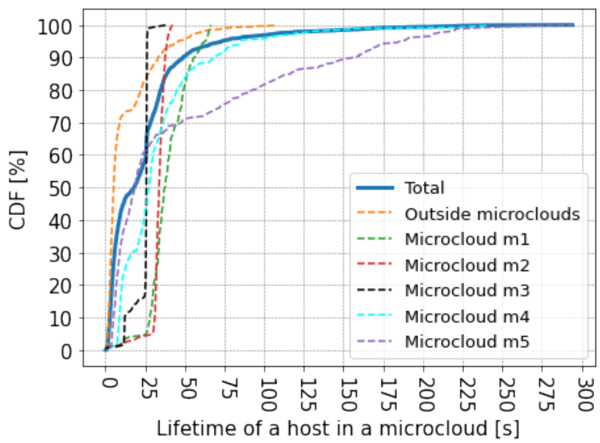


Fig. 4: Time spent by hosts in micro cloud areas.

Other simulation parameters are reported in Table I.

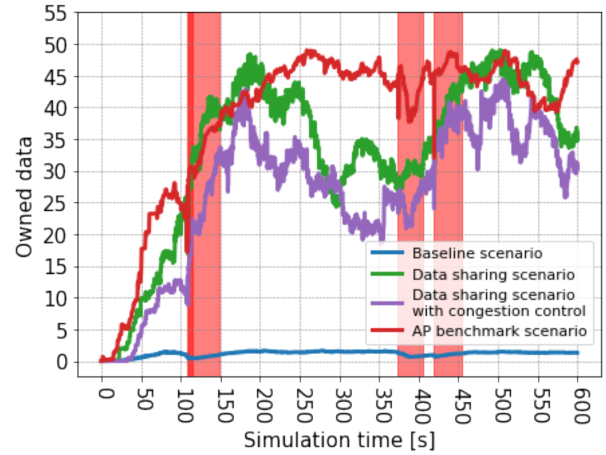
A. *Mobility Analysis*

A first and necessary consideration regarding results derived from our model is their high dependency on the chosen mobility scenario. Mobility traces used in our scope define a model with peculiar characteristics, which affects interactions between hosts and, consequently, the whole system. A clear example of this is the event of a train approaching a platform area: in a few seconds, we can observe a discrete number of new hosts popping out on the map and, a few moments later, hosts with longer lifetimes and a large number of owned contents boarding the train and eventually leaving the model. This behavior is confirmed in the mobility analysis reported in Fig. 3, where the number of hosts passing through micro cloud areas is reported for every micro cloud throughout the simulation. Red vertical bars represent incoming trains at a platform. It is possible to notice how, for every area of study, trains approaching affect the mobility environment with a spike and/or a depression in the number of hosts.

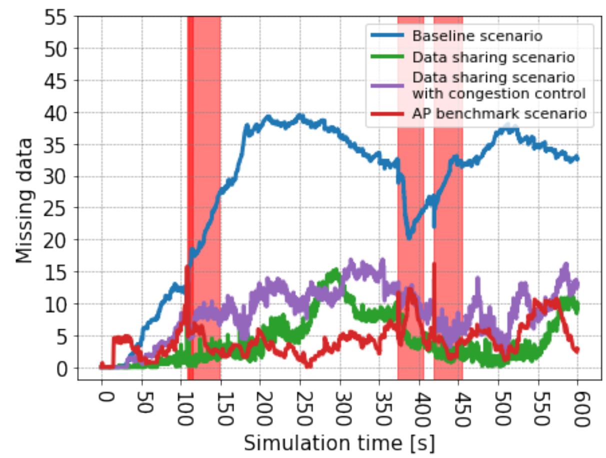
A deeper mobility study highlighting differences between the mobility of each area was performed. Fig. 4 reports the average time a host spends in every area. In particular, the thick blue line represents the overall average time a host experiences in the simulation map: 90% of hosts exit from simulation within 50 s from their initialization. A more detailed view is provided by the dashed lines, which constitute insights into the average time spent by hosts in every micro cloud area. We can observe how some areas are solely transit zones, like the north corridor or the escalators. Differently, the main hall and platform areas see hosts pause for longer periods of time. As a consequence, not all micro clouds will experience the same content sharing environment: areas observing a much greater number of hosts for a longer time are more likely to be the places for wider data distribution.

B. *Micro Cloud Performance*

Regarding content items, Fig. 5 depicts the number of owned and missing items during simulation time for all the scenarios described in the previous section. The blue line in the figures represents the first scenario where sharing data between hosts was not allowed. Since the only chance for an host to own a content item in this stage is to create it, the number of overall owned data is extremely low, while on the opposite we see the number of missing items growing up to 40, i.e., the 80% of total data in the model. Results for the second scenario correspond to green lines and show how sharing data packets between hosts improves the number of owned content items by up to 100% (50 items out of 50), while the number of missing ones does not overcome 15. The purple line highlights similar performances for the third scenario with congestion control with respect to the sharing one. The main difference between the latter two scenarios is regarding channel collisions, as described in the next subsection. Eventually, red lines represent data owned and requested by hosts in the scenario with APs. Having a few fixed stations with all the data significantly improves results, since the scenario is much less distributed. Nevertheless, high costs of installation and maintenance have to be considered in this latter case.



(a) Owned content



(b) Missing content

Fig. 5: Content items comparison between scenarios.

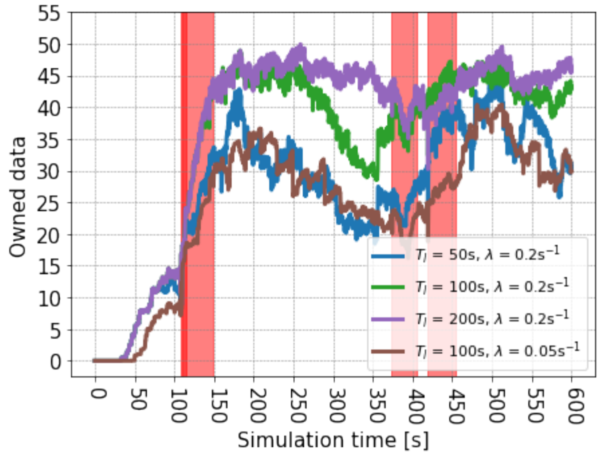


Fig. 6: Content lifetime and frequency creation analysis.

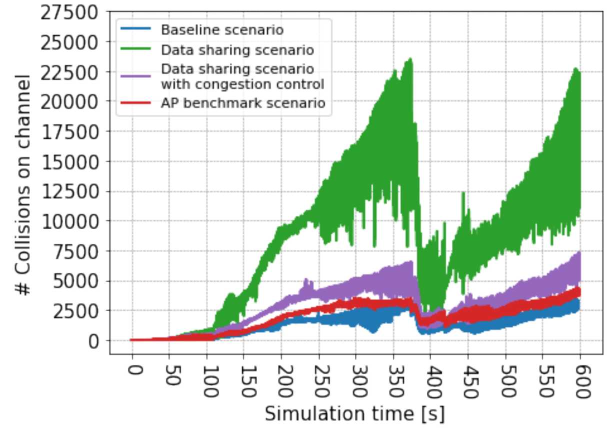


Fig. 7: Broadcast collisions on channel.

An analysis regarding content lifetime and data creation frequency is also reported in Fig. 6. From the figure, it is clear how it is possible to improve the spread of items over the map environment by increasing the content item lifetime T_l in the same scenario. Moreover, the brown line in the figure reports the number of owned content items in a scenario with a less frequent content generation rate λ with respect to others. Comparing the brown line with the green one with a similar T_l, it is possible to notice how content creation frequency has also an impact on content items spreading.

C. Wireless Channel Load

Eventually, an analysis of wireless channel load was performed and the average number of collisions over the channel media is reported in Fig. 7. In this plot, we can see the improvement introduced by the congestion control mechanism, i.e., the purple line, with respect to the green line of the second scenario. The blue line shows a small number of collisions on the channel due to the only beacon sending leveraged in the first scenario. For the last, the red line reports the number of collisions for the APs scenario: only APs are entitled to share content items in this scenario, resulting in a minimum number of channel load.

VI. Conclusions

In the present work, we propose a distributed application based on micro clouds for spreading content items in a sharing economy environment with cashback rewards for users. We thus implemented a content sharing procedure with evaluation over different scenarios. Results presented show how it is possible to achieve up to a 100% spread of content items with the described procedure. Furthermore, according to the methodology described that takes into account channel congestion, a 66% reduction in collisions over the channel is achieved. Eventually, a deep mobility study and a content lifetime and frequency creation analysis were also conducted. As future work, the micro cloud model could be further expanded into a much more large-scale scenario. We are planning to consider a mixed micro cloud scenario where vehicular and pedestrian micro clouds can share content items between each other thanks to Vehicle-to-Pedestrian (V2P) communication. A more complex study could also introduce data from Road Side Units (RSUs) in a full Vehicle-to-Everything (V2X) fashion.

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