Scaling Online Collaborative Games to Urban Level

Dario Maggiorini, Christian Quadri, Laura Anna Ripamonti
Università di Milano
Via Comelico, 39 - 20135 Milan, Italy
{firstname.lastname}@unimi.it

Abstract—**With the growing availability of personal communication devices we are witnessing a tremendous increase in the demand for mobile services based on location and context. Mobile gaming is, of course, following this same trend. Unfortunately, differently from other services, location- and context-based gaming strictly requires near-field communication to interact with nearby players in order to create teams and arenas. Since currently adopted technologies suffer from scalability (Bluetooth) or energy (WiFi) constraints, Opportunistic Networks (ONs) have already been addressed as a viable solution to involve a considerable number of players on a wider area. While massive multiplayer games are commonplace on wired networks, it is not yet clear how player experience is affected by the increased delay and probabilistic message forwarding introduced by a huge population over an ON. In this paper we address this problem by proposing an opportunistic collaborative game, which is meaningful for the category of collaborative puzzle games, and evaluating its playability and scalability by means of simulations on a real city topology.**

Index Terms–Opportunistic Networks; videogames; pervasive gaming; collaborative games; mixed reality games; urban services; scalability

I. INTRODUCTION

In these last years the growing availability of personal mobile devices with ubiquitous communication capabilities has boosted the demand for mobile services. These mobile services are nowadays typically offered based on location and context, opening uncountable possibilities for innovative application scenarios. Gaming applications are, of course, no exception. Nevertheless, the 3G networks infrastructure sometimes struggle to keep pace with location-based applications due to its limited scalability [1] and pull-based service model. A proof of this claim can be found in the PlaystationVita [2]. This mobile console from Sony has recently hit the shelves and is 3G enabled; anyway, 3G gaming is explicitly unsupported by the majority of games and does not meet the favor of many users.

In the field of entertainment applications, to organize players in teams or arenas, game developers usually adopt a near-field short-range communication paradigm where all mobile gaming devices connect to each other as in a Mobile Ad hoc NETwork (MANET). While this is a de-facto standard on the small scale, existing technologies pose severe scalability issues when moving to a larger area or connecting more players. In particular, Bluetooth does not allow more than 8 players in a 10 meters range and WiFi hardly supports ad-hoc mode on mobile game consoles/smartphone and usually drain batteries at an unsustainable rate.

One viable solution to involve a huge number of players on a wide area is by the adoption of a Delay Tolerant Network (DTN) [3] where unplanned and unpredictable contact opportunities between players are exploited to perform data exchange and forwarding. Following this approach, we could create an Opportunistic Network (ON) [4] between mobile consoles.

Games developers willing to deploy their products on an ON will be able to take advance from unplanned contacts between users: this will make the game inherently location/context dependent and will naturally scale up to a virtually unlimited number of players. On the other hand, interaction can be fast and real-time only during encounters and contact on opportunity must also be accounted as part of the gameplay. Unfortunately, as of today, it is not yet clear how unpredictable delay and probabilistic message forwarding will be affecting the gameplay on a large scale.

Since it is not possible to address the problem described above in its completeness in a single work, here we will be focusing on a specific case: the gameplay evaluation of a collaborative mixed reality game [5] in a real urban scenario exploiting the ON provided by a Public Transportation System (PTS). The idea behind this choice is to focus on games designed to exploiting existing technologies, relationships, and places as platforms to deliver a compelling and intriguing experience. In an urban environment, it is quite natural to apply this scenario to players engaged while commuting from/to their workplace or school. Furthermore, understanding this specific case paves the way for the design of games suited to foster social interaction and to promote public services such as the use of the PTS itself.

In this paper we propose an opportunistic game inspired from a real – and standalone – one as meaningful for the broader category of collaborative puzzle games. The game will be evaluated by means of simulations on the topology of a real city to understand how satisfactory can be the gameplay depending on players' encounters, movements and density. The outcomes of our study will offer hints to game developers and designers about the major technical constraints impacting on the gameplay and on game mechanics, which could also limit the structure of collaborative mixed reality games.

The rest of this paper is organized as follows. In Sec. II we provide background information and related work about ON and mixed reality collaborative games. Our proposed game is described in Sec. III, while Sec. IV provides details about the simulation environment. Section V presents and discusses simulation results and, finally, Sec. VI concludes the paper.

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II. BACKGROUND AND RELATED WORK

To the best of our knowledge there is currently no published work on the specific problem of gaming over opportunistic networks. The term "game" has been merely used to indicate game theory approaches to ON routing. For this reason, in this section we are going to provide separate discussions for ON as a technological platform and collaborative mixed reality games as an innovative and challenging application for wireless networks.

A. Opportunistic Networks on Public Transportation Systems

Despite the fact that Disruption/Delay Tolerant Networks (DTNs) have been introduced only in 2003 [3], a considerable effort has been devoted by the scientific community on their architecture [6, 7, 8, 9]. ONs are a special case of DTNs where an end-to-end path between the source and the destination may not exists and unplanned contact opportunities are exploited to implement routing/forwarding. [10, 11, 12, 13, 14]. Among ONs, networks built on top of Public Transportation Systems (PTS) have been attracting attention in recent years. Currently, research on ONs deployed over PTSs is mainly focused on performance evaluation of data distribution schemes.

Campus bus networks (e.g., [15, 16, 17, 18]) are designed to serve students and faculties who commute between colleges or from/to nearby towns. These kinds of services are usually characterized by a relatively small number of nodes when compared to a fully-fledged urban environment. The main contribution in this direction is represented by [15], where five colleges are linked with nearby towns and to one another over an area of 150 square miles.

Scaling up in terms of number of nodes, we find urban environments where a considerable number of lines is densely deployed to enable people to commute inside a city. Bus networks in urban environment (e.g., [19, 20, 21]) are usually characterized by many contact opportunities and frequent contacts. In [19], authors propose a commercial application called Ad Hoc City. Ad Hoc City employs a multi-tier wireless ad-hoc network architecture to provide elastic Internet access. Local Internet access is managed by an Access Points (AP) covering the geographical area. Messages from mobile devices are carried to an AP and back using an ad-hoc backbone that exploits buses. Authors verified the validity of the proposed approach against real movement traces by King County Metro bus system in Seattle, WA. Later on, using the same real data as for [19], the authors of [20] proposed a cluster-based routing algorithm for intra-city message delivery. Finally, the contribution from [21] uses data from the public transportation system of Shanghai to test the performance of a single-copy forwarding mechanism adopting a probabilistic routing strategy where probabilities are related to intra- contact times.

B. Collaborative Mixed Reality Games

A shared, and agreed upon, definition of "mixed reality games" still not exist, nonetheless we can describe them as "*goal directed, structured play experiences that are not fully contained by virtual or physical worlds*" [5]. Actually, they focus on exploiting existing technologies, relationships, and places as platforms for gameplay. Also, we can notice that collaborative mixed reality games can assume multiple forms, whose game-real world interfaces can range from "augmented reality" to "real environment" [22], thus including paradigms like: Context-aware Games, Alternate Reality Games (ARGs), Social Network-based games and Augmented Reality-based games. Moreover, due to the fact that they "play" with the boundaries of traditional gamespaces, mixed reality games are able to blend game mechanics with our everyday life [23, 24].

Among the most notably example of Mixed Reality Games, we can list the following examples that, beside being collaborative and often also pervasive, share one or more traits with the simulation we have set up:

- Entertainment applications that exploit sensors data – collected form cameras, accelerometers, gyroscopes, and GPS – as part of the gameplay: (e.g., Biblion and iSpy for iOS devices, Facebook, Foursquare, etc.)
- Games whose narrative is built by players using diverse media elements, and which usually require players to collaborate in order to solve puzzles/challenges (Evoke, I love bees, The lost experience, Cruel 2 be kind, Pac Manhattan, etc.)
- Games that exploits players' social networks as resources for the gameplay (e.g., Farmville, Spent and Oregon Trail for Facebook, DropIn for LinkedIn)
- Games that overlay information on some depiction of reality (e.g., Magic: Eye of Judgement for PS3, Face Riders for Nintendo 3DS, Parallel Kingdom for iPhone)

Last but not least, it is important to underline that, not only a shared definition of collaborative mixed reality games is yet to come, but the genre is also missing the benefits of a coherent body of focused investigation and practice about the design criticalities that should be properly addressed to create compelling and fun games [5]. As a matter of fact, a game designer confronting with this genre should have a clear understanding of the effects deriving from the interaction among game mechanics, technologies, and social engagement strategies at work in the game in order to obtain novel game experiences. This means, in our specific case, that the game designer should be aware of all the crossed effects and problems deriving from the design of a collaborative game mechanic, supported by a – partially – mediated social interaction among players taking place through a wireless infrastructure and issues typical of Human-Computer Interface disciplines (HCI), such as the design of effective touch screen interfaces (see, e.g., [25]).

III. MOBILE ALCHEMY

To evaluate game experience while increasing the number of player we are proposing here a proof-of-concept game by the name of *Mobile Alchemy*. Mobile Alchemy is an opportunistic collaborative game where players exploit casual encounters in order to exchange bits of information (elements) between each other and discover alchemic combinations. This game has been inspired by a game for mobile devices – Alchemy – available for Android and iOS platforms. In the original game, the player starts with a set of four basic elements (fire, earth, air, and water) and combines them together in order to get other – more complex – ones; the total number of element is 380 and the goal of the game is to discover all possible combinations. With Mobile Alchemy we are extending the gameplay making the game a collaborative activity: each player holds a limited storage of local elements in her personal device and combine them only with elements contained in another – nearby – device. When another device is in range, the player can browse its elements and try to make a new combination. If a combination can take place, the local element will be destroyed and replaced by the result while the remote element is left untouched. Combination rules and elements are exactly the same as in the original game.

Mobile Alchemy is designed to play while commuting on a public transportation system. Buses will serve both as meeting points for users and data mules. Combinations can take place on trip or at a bus stop when waiting for transit. While on trip, each player on the bus is able to combine her elements with those of all other players on the same bus. While waiting for transit a player can try to combine her elements with those "transported" by each bus stopping by, even if she is not going to catch it. Every coach will also carry around an unlimited reserve of the four basic elements to avoid players to get stuck in the game; if a player is traveling alone she can always try to make combinations with the four basic elements carried by the bus.

Whenever a player obtains a *final* element (i.e., an element that does not allow further combinations) she can discard it and replace it with one of the basic elements carried by buses.

IV. SIMULATION SETUP

In order to achieve realistic results we performed simulations using the actual topology of the city of Milan (Italy) and its actual public transportation system. Milan is a medium size town (typical for many European cities) and its PTS is a complex system extending above and below ground. Due to the underground aquifer and archaeological remains, the subway system is relatively underdeveloped while the ground transportation system spans 69 lines over 128 square Km for a total paths length of 1099 Km (8.65 Km for every square Km). The overall city structure is clearly not Manhattan-like (see Fig. 1) due to the adaptation to the old Roman historical center and the progressive annexing of small peripheral towns to the main city body.

Players will be commuting inside the city using the public transportation system. Housing in downtown is quite uncommon: the usual condition for commuters is to live in the suburbs or just outside the city and to spend the day working/studying in or close to the city center. To simulate a realistic behavior, locations will be randomly selected using a polar coordinate system with pole in the city center (Piazza Duomo); radial coordinates will be picked using a Gaussian distribution with parameters μ and σ while angular coordinates will follow a uniform distribution.

A player will spawn at her home location and move by foot using a constant speed to the closest bus stop. From there, the bus stop which is closest to the destination will be reached

Figure 1. A map of Milan with the outline of ground transportation lines used in simulations.

using one or more bus lines selected with a minimum hop algorithm (i.e., minimizing the number of transits between lines). From the last bus stop to the final destination the player will walk again. After stopping for a random interval of time at the destination, the player will leave and take the trip to go back home. On the way back the same approach for path selection as before will be applied; nevertheless, the backward path might be different due to asymmetric bus lines. Departure times in both directions are selected using a Gaussian distribution.

During experiments, players will be classified into two groups offering different behaviors: students and workers. Students leave home in the morning to move toward one of the five main universities in Milan (i.e., Università Statale di Milano, Università di Milano-Bicocca, Politecnico di Milano, Università Bocconi, and Università Cattolica del Sacro Cuore) and will move back home in early afternoon. Workers will leave home in the morning to go to the office and will come back in late afternoon.

For all players, home locations will be generated using $\mu = 6$ km and $\sigma = 2$ km. Student destinations will be obtained by randomly picking a university from the above list while offices location for workers will be selected using $\mu = 1.5$ km and $\sigma = 1$ km. Departure and return times are selected following a similar policy. Departure times in the morning will follow a distribution with $\mu = 7$ A.M. and $\sigma = 30$ min for everyone. Student will come back from school with $\mu = 1$ P.M. and $\sigma = 15$ min while workers will vacate the office with $\mu = 5$ P.M. and $\sigma = 60$ min.

To simulate the gaming activity, all players has a local storage of four slots and will start in the morning with a set of the four basic elements. While commuting, each player will keep scanning elements carried by in-range players and will make a combination whenever possible, giving priority to those leading to yet unknown elements. This behavior will simulate an exploration attitude typical of puzzle games. In order to avoid creating all compounds in a single run, players on trip can perform only one combination for each bus stop while

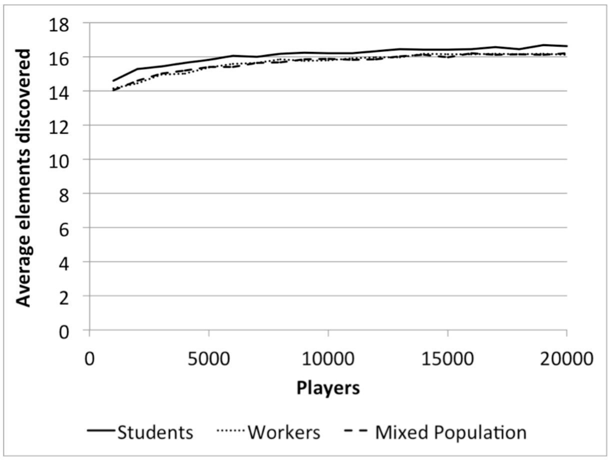

Figure 2. Average number of elements discovered by every player.

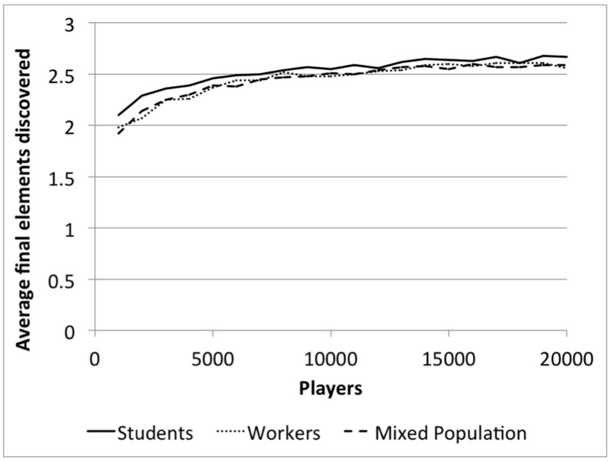

Figure 3. Average number of final elements discovered by every player.

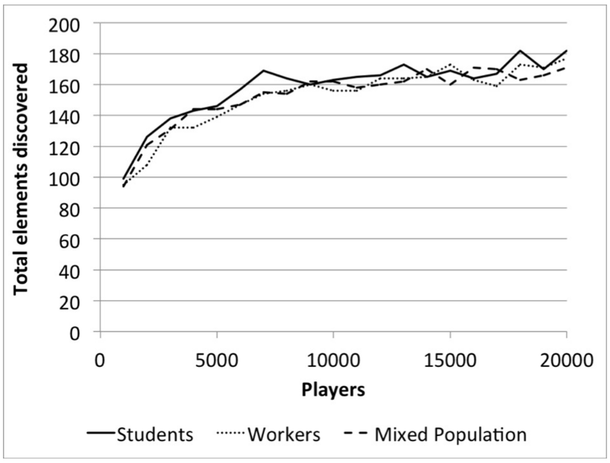

Figure 4. Elements discovered by all players.

players waiting for transit will be allowed one combination for each bus stopping by.

To provide connection, we assume access points to be deployed on buses and to work as hubs between users; this way there is no need to manage ad hoc networks (WiFi or Bluetooth) between phones. A user simply registers while boarding and the access point will provide a local area network for devices discovery and data exchange.

With respect to data transmission, in our experiments we considered IEEE 802.11b technology. Available bandwidth is 11 Mbps and the radio range is 100 m. Transmission is accounted using a token bucket model. Communication takes urban canyons into account; we consider only line-of-sight contacts between stopping buses and users waiting for transit.

All PTS operations are simulated using the actual timetables from the PTS operator website [26] as of February 2010.

Simulations are performed using URBeS (Urban Routing Backbone Simulator): an ad-hoc simulator presented and validated in [27] and [28].

V. Performance Evaluation

Experiments have been performed varying the number of players from 1,000 to 20,000 and observing gaming results at the end of the day. In each of the following figures, three graphs will be presented depending on how the population is composed: (*i*) only students, (*ii*) only workers, and (*iii*) mixed students and workers. In the mixed case each player type will be 50% of the total population.

The first performance index we consider is the average number of elements discovered by each player during the day (see Fig. 2). This index is meaningful about how much the player gets involved in the game and, assuming she takes pleasure in completing the game as much as possible, her level of rewarding. As we can see, despite the fact that the population has been increased twenty times, there is not a significant increase in the discoveries, which are going up from 14 to 16. Moreover, there is not much difference between the tree populations: it seems that user habits are not very significant for the game. Similar conclusions as above can be drawn observing the average number of final elements discovered (Fig. 3), shifting from 2 to 2.5. Both these indexes seem to indicate a potentially low player engagement in the proposed game.

From a game design standpoint, the situation we just described poses severe restrictions to the game mechanic. Players get usually rewarded when completing sequence of puzzles or on reaching the end of a sequence of chained quests. Collaborative urban games should then be designed with limited requirements – in term of time and actions to perform – to get in-game achievements.

Let us now consider Fig. 4, where the total number of discovered elements is reported. As we can observe, also this index is bounded and independent from the player habits. Moreover, the maximum number of discovered elements is well below the game limit (380). This is a clear indication that game performances are upper-bounded by some environment constraint rather than the number of users. Confirmation of this claim can also be found in Fig. 5, which is showing that the activity in the system keeps increasing linearly with the number of players; i.e., the system is not overloaded. Furthermore, if we compare Fig. 2 and Fig. 4, the number of players does not seems to be a scale factor for the increases in the two graphs. One possible explanation for this behavior is that increasing the

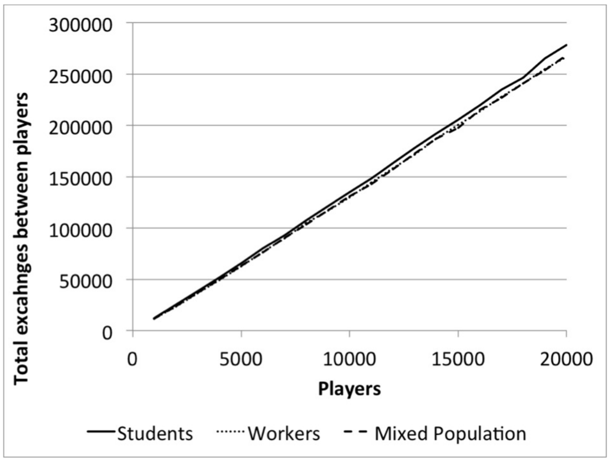

Figure 5. Total number of combinations performed by all players.

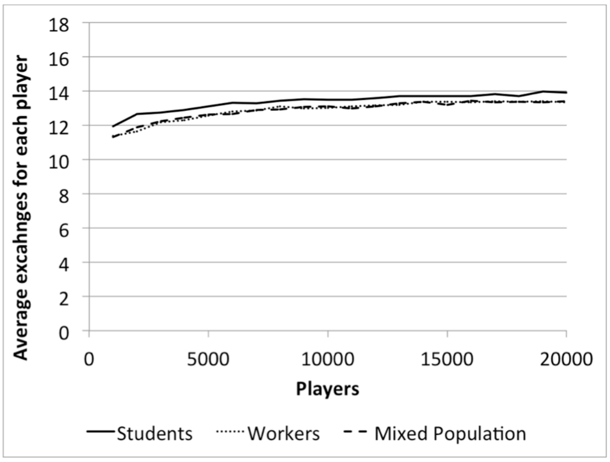

Figure 6. Average number of combination performed with other players.

population does not pushes for more discoveries but makes discovered elements to spread more quickly across the city; in this way a few new elements will be promptly made available to a broader audience. In other words, players are using the system to build the same elements over and over. From a game design point of view, this behavior seems to support games that are more oriented to collaboration rather than competition; moreover, offered content does not really need to be proportional to the number of players or their density.

The only other likely reason for performance limitation is that players have actual problems in meeting and playing together. This may be due to a number of reasons: from the constrained movement pattern imposed by the PTS to the fact that an extremely high density of players is required: 20,000 users in a single city can make of any mobile game an instant classic; nevertheless, they still will be less than 1% of the commuting population of Milan. Figures 6 and 7 support this claim.

In Fig. 6 the average number of successful data exchanges between players is reported. As we can see, the number of combinations among players is very limited and follows a profile quite similar to Fig. 2. This means that if another player is in range it is very likely to discover a new combination thanks to the complex element this player is carrying. On the other hand, Fig. 7 provides the share of combinations a player is required to perform alone (i.e., using the basic element transported by the bus). With a low user population, up to 35% of the combinations are performed with a bus because, most probably, there are no other players around. Increasing the population brings interaction with buses down to more acceptable levels.

Following Fig. 6 and Fig. 7, game designers should try to keep the requirement for opportunistic interaction between players to a minimum. With this kind of games on an urban scale we see as unlikely that data exchange between players can be in the core of game mechanic, but rather it could make a good addition to extend the single player experience.

The last performance index we are going to consider is at what time each player performs the last combination. This index can help us understand the actual engagement of users in the game. The cumulative distribution function of the time of last successful combination in the case of 10,000 players is reported in Fig. 8. From this figure, we can see another constraint in our system: 70% of players stop playing in the morning upon arrival at school or office. This index is a bit lower if we consider a population of students only. Since, as we already discussed, the system is not overloaded, the lack of new

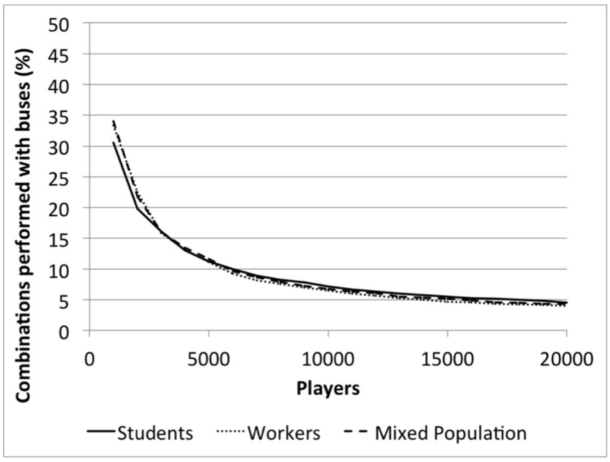

Figure 7. Percentace of combinations users are performing alone, using elements carried by buses.

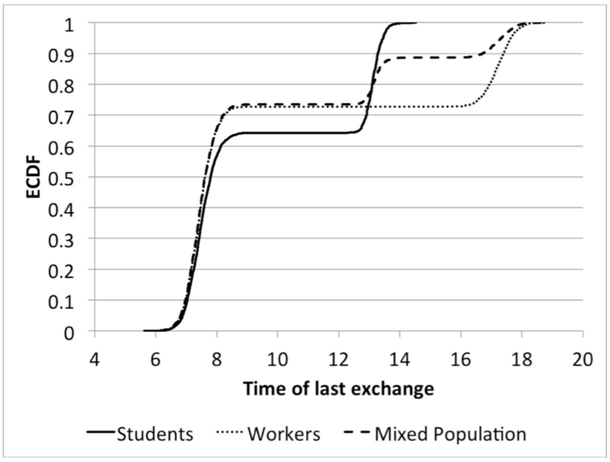

Figure 8. ECDF of the time of last succesful combination.

combinations in the afternoon might be due to many users carrying the same – complex – elements and generating a deadlock. The only way out from this state could be to distribute new – and easy to combine – elements during lunchtime. From a game designer perspective the game should not be conceived as a closed system: a continuous stream of content from the outside is required as a stimulus to keep the game rolling. If this stimulus is not provided, game evolution could quickly reach a steady state and stop there.

VI. Conclusion and Future Work

In this paper we addressed the problem of understanding playability of online collaborative games when scaling up to urban level. In particular, we have been focusing on a collaborative game deployed on the opportunistic network that could be provided by the public transportation system of the city of Milan, Italy. Simulations allowed us to point out several potential design issues. In particular, among these issues, we found that the number of actions/moves available to players does not scale with the population and that gameplay cannot be built solely on interaction among players.

Future evolutions of this work include both theoretical and practical aspects. First, we need to identify some general guidelines for game designer to create an effective gameplay to be used in urban-sized games. Second, other map topologies and extensions need to be taken into account in order to understand scalability with infrastructure complexity. Last, collaborative puzzle games usually require coordination from players to achieve shared goals; events synchronization over an ON poses a serious challenge and we need to extend existing mechanisms such as the ones proposed in [29] and [30].

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