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Abstract. Location-based applications suffer from many drawbacks related to the underlying infrastructure necessary to support this functionality. This work analyzes location-based games for cellphones, in order to investigate possible approaches to handle technology limitations in this kind of application.

Keywords: Location-based games, pervasive mobile games, uncertainty handling policy, context-awareness.

Resumo. Aplicações baseadas em localização possuem uma série de limitações tecnológicas inerentes à infraestrutura usada para se prover essa funcionalidade. Este trabalho realiza uma análise de jogos baseados em localização, para telefones celulares. Essa análise tem como objetivo investigar alternativas para se lidar com essas limitações, através de exemplos.

Palavras-chave: Jogos baseados em localização, jogos pervasivos móveis, política de tratamento de incertezas, ciência de contexto.

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1 Introduction

Mobile devices (especially smartphones) are ubiquitous devices. They are everywhere, anytime, in the hands of many people. For example, in Brazil (where the present work was developed) there were more than 200 million mobile phone subscriptions in late 2010, according to the ANATEL, the Brazilian National Telecommunications Agency (Anatel 2011). This is more than the population of Brazil (~ 190.73 million people), according to the 2010 population census (IBGE 2011). According to the GSM Association, there are more than 10 billion GSM subscriptions worldwide (GSMA 2013).

Current mobile devices are equipped with a multitude of sensors. For example, inertial sensors (accelerometers, gyroscopes, etc.), high resolution cameras (5 MP+), multi-touch screens, light sensors, proximity sensors, magnetometers, GPS, NFC readers, WiFi, and Bluetooth.

Smartphones are always-connected devices by definition. The connectivity capabilities of smartphones extend beyond global networking through cellular operators. Smartphones also are able to use local networking through Bluetooth and WiFi technologies. In the case of Bluetooth, mobile phones with this technology can be already considered common-place. Also, smartphones are able to provide network access to other devices, becoming hotspots.

Location-based games aim at using the geographic device position as a game data. This kind of game makes it possible to explore an important (and significant) feature of mobile devices: high mobility. We understand as “mobility” the capacity to use services through networks while the user is in transit.

In practice, the process of determining location (and other information derived from sensors) has several limitations. These limits stem from technical constraints regarding the technology involved in determining the sensed information, generating uncertainties (e.g. context acquisition and processing). As examples, variation in cellular operator coverage, network communication delays, information loss, limited sensor precision, interferences related to the environment (physical objects that block signals, tall buildings, mountains, and others) (Broll and Benford 2005).

Location-based game designers need to take uncertainties into account when developing a project. This work aims at analyzing some approaches to handle uncertainties in location-based games, through case studies. Although this work analyzes location-based games, the uncertainty handling policies would apply to context-aware games in general (games that use sensor data in the gameplay).

This work is organized as follows. Section 2 describes some location methods in location-based games. Section briefly 3 describes some approaches to handle uncertainties. Section 4 describes the uncertainty handling policies in more detail, through case studies. Section 5 presents the conclusions of this work.

2 Location methods

Location methods for smartphones use several different technologies. We have identified three categories in the examples we had studied: methods based on cellular network, absolute methods (not dependent on cellular network), and implicit (mixed) methods. Next sections describe some of the available methods in these categories.

2.1 Methods based on cellular networks

These methods use devices based on GSM networks. The cellular network is divided into several areas, named cells. Each cell has an identifier. Figure XXX illustrates a scheme with three highlighted cells (C1, C2, and C3). The BTS represents a base station that provides coverage to a number of cells. MS represents a mobile station (a mobile phone). Although in Figure XXX the cells have the same size, in practice cell size is variable.

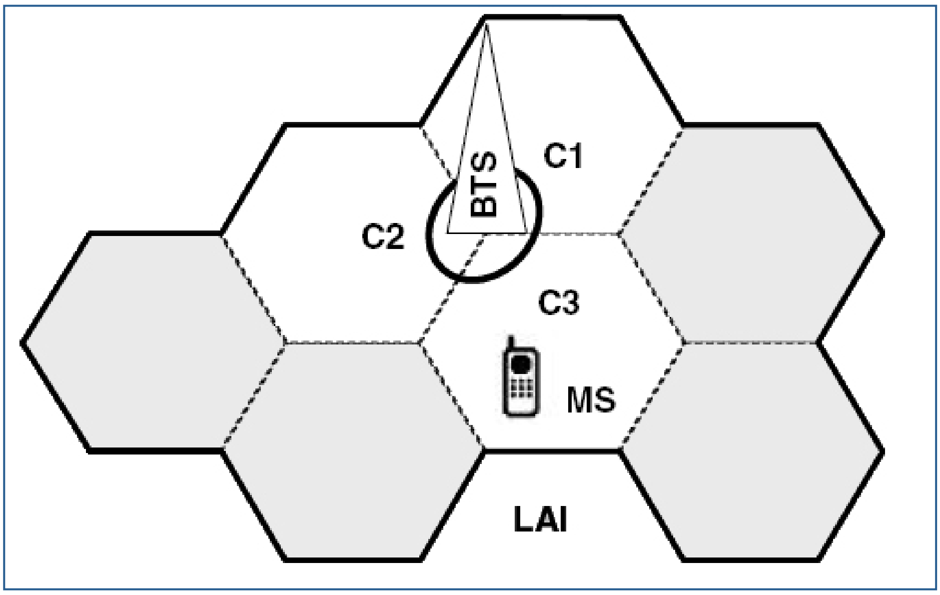

Figure 1: Simplified cellular network example (Trevisani and Vitaletti 2004)

The cell-id method uses the cell ids to estimate the device position based on the cell location.

Telephony services already use this method to locate the device, so it does not require additional investments. The precision is variable, because it is directly affect by the cell size. The cell size varies from meter to kilometers (Trevisani and Vitaletti 2004). The time it takes to estimate location using this method is about 3 seconds (Rashid *et al.* 2006b).

2.2 Absolute methods

The methods in this group use means to access location without relying on cellular networks, generally.

For example, there are devices equipped with GPS sensors. The GPS system represents a global positioning system that uses satellites to provide location data. This system connects to at least three satellites, and uses the distance between the device and the satellites to estimate the device location.

Hence, the device needs to have a clear view of the satellites for the GPS system to work correctly. For this reason, the GPS system has limited coverage in closed environments and in dense urban environments (due to tall buildings).

GPS precision ranges from about 2 to 10 meters (Rashid *et al.* 2006b). The time it takes for the device to connect with the satellites is variable, and can be very long (from about 10 seconds to several minutes). Another problem (specific for mobile devices) is the battery use required for this operation.

2.3 Mixed methods (implicit)

This category covers methods where the smartphone interacts with some other device or system (that has a known location) in order to estimate the smartphone location. These methods can be regarded as hybrids (or mixed).

The A-GPS (assisted-GPS) system is an existing variation created to minimize some problems in the GPS system. The A-GPS system requires using the cellular operator network to quick start the connection to satellites. In this system, servers installed in cellular base stations store their (fixed) GPS coordinates. Then, the device is able to estimate its position relative to the base station where it is connected by connecting to the servers and querying their location information. An advantage this method presents is to reduce the time it takes to estimate the device location, because servers in the base station perform part of the process. According to (Rashid *et al.* 2006b), the time it takes to estimate location with this method is around 5 seconds. Another advantage is the possibility to estimate location in places where the traditional GPS does not work (like closed environments).

Another possibility is using WiFi networks, Bluetooth devices, two-dimensional barcodes or RFID tags as intermediate solutions to base device location estimation.

Devices equipped with Bluetooth and WiFi technologies are commonplace nowadays. As a consequence, mobile devices are able to interact with WiFi routers or fixed Bluetooth devices to infer partial location information. An advantage of using Bluetooth as a foundation of a location system is greater tolerance to signal variation and low energy consumption (Rashid *et al.* 2006b). However, Bluetooth networks have low coverage (about 10 meters), and the number of devices supported in a single Bluetooth network is limited to 8 (although it would be possible to build a combination of Bluetooth networks to support more devices).

When using 2D barcodes, the use location is determined when the device reads the barcode. As the barcode has a fixed position, it is possible to have the device position at that moment. Barcodes come in several shapes. Examples are Datamatrix (DM), QuickResponse (QR), Semacodes e ColorCodes. Figure 2 illustrates a Semacode.

Figure 2: A Semacode

The RFID tags can be either active or passive. Active tags have their own energy sources and transmitters, while passive tags do not have these features. As passive tags do not have their own energy sources, they are candidates to use in large scale for environments where it is not possible (or desirable) to use independent energy sources (as batteries).

These devices can be read-only (e.g. as a tag that transmit information) or not. RFID tags have an advantage over barcodes because unlike barcodes, the tags not require processing to obtain the data. Figure 3 illustrates a RFID tag.

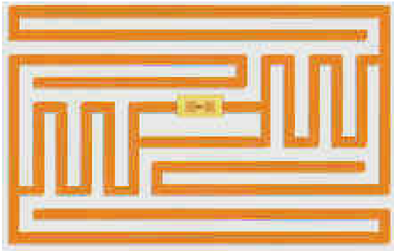

Figure 3: A RFID tag

3 Strategies to handle uncertainties

Benford and co-authors (2006) identified five general strategies to handle technology limitations (uncertainties) in location systems. We believe these strategies apply also to other systems that use sensors to capture data from the environment. The strategies are: remove, hide, manage, reveal, and exploit. These categories are not rigid. In some cases, they may overlap. This section provides an overview on these strategies, and Section 4 presents examples on applying the strategies.

The *hide* strategy consists in minimizing the problems caused by the uncertainties. A possible alternative to implement this strategy is not requiring more precision than the sensors offer. An example is using ambiguous metaphors to refer to an object position in the world. Another alternative is having players use an ambiguous communication channel to talk about location, as audio.

The *remove* strategy could be considered as a special case of *hide*, where the all possible problems could be eliminated. For example, a game relying on GPS systems could restrict game playing to places where GPS signal reception is good (like open places and environments with few buildings). Another possibility would be investing in a improving an infra-structure, but this is not always feasible (due to economic or technical issues).

The *manage* strategy expects uncertainties to show up anytime, providing alternate means to keep the game running when they happens. Ideally, the possible measures should not interrupt the game not make players aware of it. For example, in a game taking place indoors players would probably expect that the game knew about the physical limits (e.g. the different actual rooms). However, location systems do not know about physical limits because they usually work at a lower level (e.g. sensing signals). In this sense, the game would try to "correct" the context data trying to match players' expectation of physical limits.

The *reveal* strategy consists in letting users know about the uncertainties, without taking any measures to correct them. For example, mobile phones usually display the operator signal strength in the user interface. In this case, the user becomes aware of the problem (e.g. low signal, for example) and acts accordingly (e.g. move to another place with better signal).

The *exploit* strategy consists in exploring uncertainties deliberately, making them part of the game. In this regard, this strategy welcomes uncertainties, assuming that they are inevitable and therefore should be integrated into the application.

4 Case studies

This section describes some location-based games that uses smartphones, and analyses how these projects handle technology limitations and uncertainties.

4.1 Botfighters

Botfighters (Sotamaa 2002) was probably the first commercial location-based game for smartphones. In this game, players took control of robots and their mission was to locate and battle other robots. The game had a web module (running on a desktop computer) that players used to configure their robot. The module that ran on smartphones was responsible for locating and battling the other players. Figure 4 illustrates these modules.

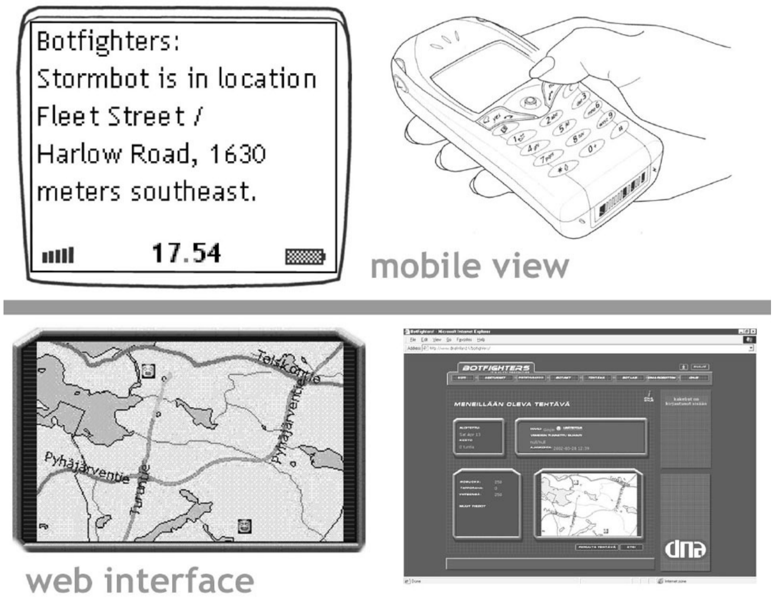

Figure 4: Mobile and web modules in Botfighters (Sotamaa 2002)

4.1.1 Strategy: Hide

In the mobile module, players interacted with the game through SMS messages. The game had specific commands to locate opponents around the place where the player was. There were also messages to attack a specific opponent. As players used smartphones, it was possible to locate them using the network operator infra-structure. However, it was necessary to send a SMS message and to wait for a reply, players experienced huge delays to see the results of their actions.

Botfighters used the cell-id method to estimate the player location. The communication of location information in the game is imprecise and ambiguous (see Figure 4), which is adequate to the precision offered by the cell-id method. Also, Sotamaa (2002) remarks that this representation is good to handle privacy issues, as it is not possible to provide the exact location of a player. Being based on the cell-id method for location, this game should work better in areas where the cellular network has good coverage (like in dense urban centers). Otherwise (like in rural areas, for example) the game would not work well (because network cells could be too distant from each other).

Botfighters did not require that players meet each other in person. As a consequence, physical interaction was not necessary in the game. As a matter of uncertainty handling, this is relevant because requiring players to meet each other would call for a much precise location system. This also helps in minimizing the effects of SMS message delays. Players interacting in person would expect messages to take effect in real-time, which is not the case in this game.

In this sense, not having players meet physically and using an imprecise way to communicate location information helps in hiding the worst effects of location estimation and network delays.

4.2 Mogi

Mogi (Joffe 2007) was a commercial treasure hunt game unveiled in 2003, and the main goal in the game was to collect virtual items. Those items are scattered in a map that corresponds to streets in Tokyo. The players have to walk around the streets to find the physical location of the virtual items. The player is able to “capture” a virtual item if he is within a radius of approximately 400 meters from the item location. The game has a mobile module and a desktop (web) module. Figure 5 illustrates the mobile module.

Figure 5: The mobile module in Mogi operating in “radar” mode (Hall 2004)

Players are able to interact with each other physically, when it is possible to exchange items to build collections. The goal is to accumulate the greatest amount of points possible, thus completing the collections.

The web module has a city map that displays the positions of players and collectible items. Players use the web module to communicate with players using mobile devices through instant text messages. This feature makes it possible to create collaborative activities for the players. Figure 6 illustrates the web module.

Figure 6: Web interface, with 3D map (Hall 2004)

It is not very clear which location technology Mogi used. Considering the available technology at the time the game was unveiled, the game probably used cell-id. Mobile devices equipped with GPS sensors were not common at that time.

4.2.1 Strategy: Hide

The game uses an ambiguous definition for "capturing an item": the player captures an item if he is around 400 meters from it. This definition is "precise enough" to hide the imprecisions of the location system.

The mobile module uses a "radar" to locate other players and items. This radar interface does not display precise maps, just "positions". Hence, the game has great control on how it presents this information to players, minimizing possible inconsistencies that having a precise map would have (like overlapping the virtual and physical locations precisely). The web module goes in the same path by presenting a stylized map including players and objects.

4.3 The Drop

The Drop (Smith *et al*. 2005) is a conceptual game in the style of "capture the flag". This game was designed for a controlled indoor environment. The game maps the physical location to the virtual world of the game.

There are two teams in this game. A team is responsible for hiding a virtual briefcase, while the other one needs to find that object. The briefcase does not exist as a physical object. Each team has a leader who does not act in the game physically, playing from a remote location. The leaders are able to communicate with their teammates as a coordinator. The leaders also are able to see a game map with the position of all their teammates.

Another task that the team hiding the virtual briefcase has to do is to hide themselves and outwit the members of the other team. The application running in the mobile phones provides commands to find opponent players in the environment. The location system in the game is based on radio beacons.

Figure 7 illustrates a prototype user interface in The Drop. The green points represent teammates, while the red are presents an area that the opponent players occupy.

Figure 7: Prototype user interface in The Drop (Smith *et al.* 2005)

4.3.1 Strategy: Remove

The Drop uses the *remove* strategy by restricting the game area to a pre-determined and controlled place. The location system in The Drop uses a combination of radio beacons and wireless networks (WiFi or cellular) as data source. This solution requires calibration, however. In other words, it requires a pre-processing stage to adjust the system so that the precision is acceptable. This approach has some consequences:

- It is necessary to perform a pre-processing stage to position the beacons and other sources of location data. This process can be slow and costly.
- It is necessary to have an appropriate and dedicated place for the game session. The variables involved in the deciding the proper place could go beyond economic factors. For example, The Drop is played in a mall. It is necessary to consider if the place owners agree with having a game session, and how the game would affect non-players that have nothing to do with the game.
- Transferring the game session to another place might not be trivial.

Smith and co-authors (2005) comment that they limited the game playing area for practical reasons. They argue that having a wider game playing area would require a precision level that would be costly to achieve.

4.3.2 Strategy: Manage

As The Drop tries to map a virtual map to a physical place, it must handle the issue that location systems are unaware of physical limits in indoor places. The location system works at a lower level – radio signals.

In this sense, the application would have to monitor the location system and correct "invalid data" (data that mismatch the physical limits) before handing them to the users. On a simpler level, this could be filtering "impossible locations". As an example, if a game takes place indoors, the game would need to "correct" sensed data if these data report a position that is located outside the indoor place. This could happen due to imprecisions inherent to the sensing process.

4.4 Insectopia

Insectopia (Peitz *et al.* 2007) is a game where one or two players collect virtual insects. The main goal is to build the most valuable insect collection. Players are able to accomplish this by competing or collaborating in pairs. Another option is players exchanging insects among themselves.

This game uses the MUPE framework (Suomela *et al.* 2004) and GPRS connections to communicate with the game servers.

The virtual insects in the game correspond to Bluetooth devices in the real world. Any Bluetooth device could be used as an insect, from a mobile device to a printer. The virtual insects have a time span of eight days. After this period, they "die". Hence, players need to keep on playing to maintain their collections. However, considering the servers or the mobile client, it is not very clear who is responsible for mapping Bluetooth devices to insects.

To accomplish the ultimate game goal, the players need to wander around searching for Bluetooth devices. According to the Insectopia design, a certain device will always correspond to the same insect. In other words, if a player goes to place (like a cafeteria) and finds a specific kind of insect, he will find the same insect there if the comes back later (assuming the Bluetooth device is still there). This brings some "determinism" to the game, which can have some implications in playing behavior.

This game differs from other location-based games because it does not use player location in the gameplay. Instead, it is possible to locate only the insects. Therefore, players need to use other channels to interact with each other (like websites, emails, phone calls, and others). Figure 8 illustrates two client module screenshots.

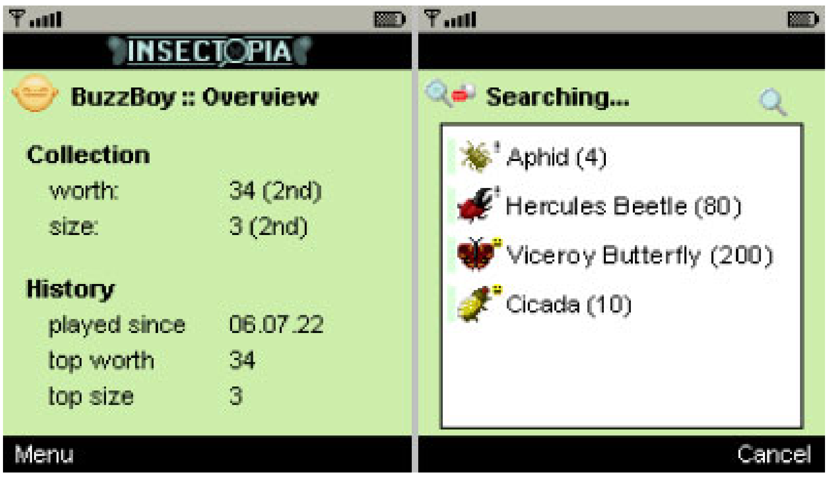

Figure 8: Insectopia screenshots (Peitz *et al.* 2007). Overview and statistics (left). Searching for insects (right).

4.4.1 Strategy: Remove

Peitz and co-authors considered several alternatives for the insect location system. They discarded GPS as there were not many devices equipped with GPS sensors at that time. They discarded location systems based on cellular networks because this would require them to provide a solution to integrate different network operators, which was a practical problem at the time the game was develop. They discarded implicit methods (as using photos from camera) due to the computational cost to process the images and because players could cheat. Hence, they chose Bluetooth. Some interesting consequences about this choice:

- There were a lot of devices already equipped with Bluetooth. This means the potential user base was huge, not requiring additional investments to deploy the game;
- The game design based around Bluetooth eliminate uncertainty issues related to other location systems (availability, signal quality, intermittent connectivity);
- As the game does not use player locations, thus eliminating issues that could be generated from uncertainties in location systems. In particular, if the players want to communicate among themselves, they need to find ways to do it without relying on the game.
- The game requires players to have a proactive behavior in searching for Bluetooth devices. This allows players to have greater awareness of technology aspects[1] in order to complete the game goal.

4.5 PAC-LAN

PAC-LAN (Rashid *et al.* 2006a) is a location-based game inspired by the original PAC-MAN. In this version, players use a physical area (the Lancaster University campus) as the game area. Rashid and co-authors chose this location for the game because its structure resembles a labyrinth, according to them.

Five players take part in the game. One of them is the main character (PAC-LAN), and the other four are the ghosts. As in the original game, the main character has to collect pills and run away from ghosts. The goal of the ghosts is to catch the main character. All players wear vests with attached RFID tags. Players use these tags to detect ("catch") each other. The pills are physical disks with attached RFID tags. The pills are scattered through the campus area. The players carry smartphones equipped with RFID tag readers.

The players "collect" pills by reading a RFID tag on a disk with their smartphone. A player captures another when his smartphone detects the player's RFID tag. Figure 9 illustrates two players in the game.

1 As getting to know what Bluetooth is and how to use it.

Figure 9: PAC-LAN players. The PAC-LAN character (left) and a ghost player (left) (Rashid *et al.* 2006a)

The game client module runs on mobile devices and is responsible for displaying information as the player locations. This module was implemented in J2ME and communicates with the game server through GPRS. The game determines the PAC-LAN's location when he interacts with a pill. The ghosts interact with the pills to retrieve information as the last known PAC-LAN location.

Figure 10: Client module screenshots (main character view) (Rashid *et al.* 2006a)

4.5.1 Strategy: Remove

The location system in PAC-LAN helps to eliminate problems related to the location system availability. Some consequences of their approach:

- Location estimation in PAC-LAN is passive, from the location system point of view. A player needs to interact with the RFID tags to update his position in the game. When he does it, the other players will be able to know his position. If a player does not do it (deliberately or not), his position in the game will be wrong. Hence, it is necessary to trust the players;
- The reported locations are very precise, as the RFID tag positions are known. The authors commented that they tried to use GPS as the location system, but using it was unfeasible due to the high degree of shadows in the campus. As a consequence, connecting to GPS satellites took a very long time. An advantage of using RFID tags over GPS is the possibility of positioning pills in places that GPS is unable to detect;
- It is necessary to configure the place previously before a game session. In this case, it is necessary to position all "pills" in the campus. In this specific example, the place where the game session happens needs to have a suitable physical structure to support the gameplay (e.g. to resemble a labyrinth).

The authors chose GPRS as the network technology for these reasons:

- GRPS connection was already available through the cellular operator network, not requiring additional infrastructure (as WiFi deployment);
- The GPRS network coverage in the campus was adequate for the game purposes;
- As the players would have to run around the campus while playing, the GPRS technology was more tolerant to signal variations that this kind of situation could entail. According to Rashid and co-authors, using RFID tags for these kinds of situations is adequate.

4.6 Tycoon

Tycoon (Broll and Benford 2005) is a multi-player game where the goal is to collect virtual items and then gathering the highest score possible. The game takes place in city streets and use GSM cells as game "locations". The game defines two kinds of locations: resource location ("the mines") and item locations ("brokers"). Figure 11 illustrates this division.

The mines provide "coins" that players can use to buy items. These coins can be "gold", "silver", and "copper", having different values. The mines produce unlimited resources, and players do not compete for these resources among themselves.

The brokers have items that players can buy. These items exist in a limited supply, with various types and values. An item is bought by the first player that reaches it, who earns the correspondent points. When there are no more items to be bought, the game is over.

The game has a client and a server module. The client is responsible to informing the player about his location (mine name, for example), helping in navigation, and informing the current score. The server is responsible for keeping the global game state (which items are free and which items have been bought). The clients are able to get an updated snapshot of the global game state by querying the server about this information.

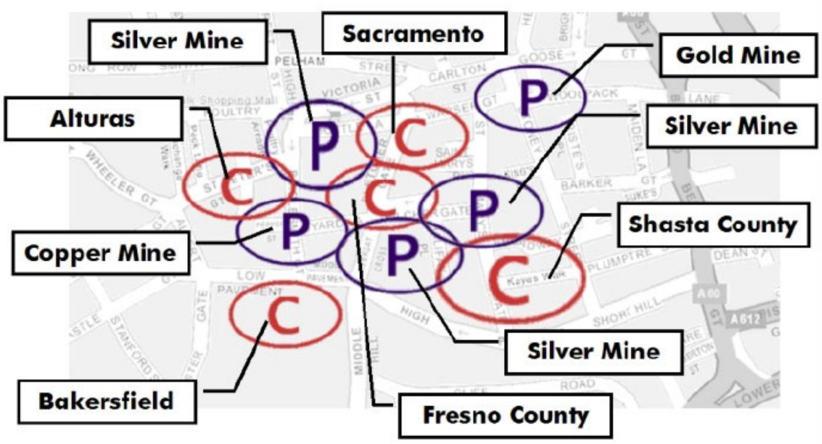

Figure 11: Mines ("P") and brokers ("C") in Tycoon (Broll and Benford 2005)

4.6.1 Strategy: Exploit

This game incorporates uncertainties in the game, instead of fighting them. For example, instead of partitioning a physical place to use as the game world, the game uses a partitioning already available (the GSM cells). The game does not use maps to display location information.

When a player moves from one cell to another, the game informs that this event happened and tells the player if he is into a mine or broker. The game does not display a "global world map". This helps to hide the uncertainties about the cell size and location (GSM cells are not static – their area varies through time, according to the authors). Displaying a map in this case would be difficult. Figure 12 illustrates a sequence when the player transits cells.

Figure 12: Area transition (Broll and Benford 2005)

The deliberate exploitation of uncertainties in mobile applications is known as "seamful design" (Broll and Benford 2005). A "seam" is anything that disturbs the mobile experience. As examples, network coverage variation, signal quality variations, and location system imprecision.

The "seamless" applications try to apply the hide, remove, manage and reveal strategies. In other words, seamless applications regard uncertainties as undesirable and needing corrections. On the other hand, "seamful" approaches regard uncertainties as unavoidable, trying to integrate them into the application.

The idea of seamless applications seems to have originated in the original ubiquitous computing by Mark Weiser (1991), which says something like: "to integrate computer into the environment, so that people use them efficiently and unaware of their presence". However, different components in the sensor and networking infrastructure have technical limitations that cause "seams", which is something that cannot be eliminated entirely (at least in current technology). Users perceive these limitations as inconsistencies, ambiguities, and imprecisions.

According to Broll and Bendford (2005), there are three stages in designing a seamful application: understanding which seams should be considered, how to present these seams to users, and designing interactions with these seams.

In Tycoon, the seam that exerts the highest influence in the game is network cell coverage. The game handles this seam by assigning roles to the cells and by not presenting a cell-based map (this would be imprecise due to cell size variation and cell overlapping). The player does not know exactly about cell limits. The game presents a series of "areas" to the player (mines, brokers), abstracting the concept of "cells" (which is really an implementation detail).

Another issue the authors point is having the players connect to a central server to know the global game state. At first, players would have to contact the central server using GPRS connections (the technology available at the time the game was developed). Hence, keeping a consistent game state would require pushing all updates to all players often. This could result in high network traffic and high cost (as using GPRS was costly at that time). Also, this assumed that GPRS connectivity was reliable and had good coverage most of the time.

In order to minimize this problem, the game designers considered these issues as artificial seams, integrating them into the game. Hence, the game does not require players to have the latest updates to play the game. The game also does not broadcasts updates to players. Instead, the game encourages players to stay in "offline mode", collecting more coins in order to make better transactions. For example, an item in the game is worth more if the player buys it with more valuable coins.

The players must consider the tradeoffs of being in offline mode. For example, a player may see an item as available when it has already been bought by another player. Hence, possible problems (GPRS cost, coverage and quality) become strategic elements in the game.

5 Conclusions

Using smartphones and mobile devices for location-based game applications presents some advantages:

- There is a huge user base;
- Smartphones are connected devices by definition (due to cellular operators). Other kinds of mobile devices may require other paths for networking (WiFi) that might not be readily available.

Location-based games are an emerging game genre. The huge smartphone user base is important for creating a critical mass for location-based games and context-aware games in general.

This work analyzed some approaches used in location-based systems for academic and commercial projects.

Handling uncertainties (technological limitations in sensors and networking) is among the main challenges that game designers must tackle in this field. In this regard this work analyzed strategies that some games applied to handle uncertainties. These strategies can be: remove, hide, manage, reveal, and exploit limitations.

Although the literature regards the *hide* and *remove* strategies as distinct, we see the *remove* strategy as a special case of *hide*. Both strategies aim at minimizing the worst effects of uncertainties. The *manage* strategy consists in living with the "problem", while fixing it when it happens before the user notices it. The difference between the *reveal* and *exploit* strategies is that *reveal* lets users know about the "problem" and hands to the user the decision about what to do. On the other hand, the *exploit* strategy integrates uncertainties deliberately as a "game feature". The *exploit* strategy is the foundation of what became known as "seamful design", which considers that uncertainties are unavoidable and thus the best strategy is to use them to improve user experience.

Regarding the strategies, we cannot say absolutely that one is "better" than another because this depends on the game design goals. However, the game design must take these issues into account from the upfront.

Regarding methods used to determine location, the cell id method is a "cheap" alternative as it is already present in cellular networks. However, precision may fall short. Using GPS is useful in outdoor areas. Using Bluetooth is an interesting option due to the availability of Bluetooth in smartphones.

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