On the New Architecture of Location-Based Services

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***Abstract* — This article discusses an alternative programming model for services that use location information. The paper proposes a new architecture for such services, which does not require users to share information about their location with service providers (services). This architecture is based on the author's proposed network spatial proximity model, where geo-computation is replaced by direct proximity measurement. This approach explicitly assumes that most services, using location information, describe (provide) some local services. Accordingly, geo-coordinates are used only for calculating proximity when searching (selecting) offers. It opens up the possibility of replacing geo-coordinates with direct measurement of proximity. Within the network proximity model, geo-computation is replaced by direct proximity definitions. And it is proposed to form this measurement of proximity based on the physical availability of signals of wireless network nodes, thus building cyber-physical systems.**

I. Introduction

Services using location information (in the English-language literature LBS – location-based services) are among the most demanded for mobile users. They find their application in B2C, B2B, and C2C areas. Geo-data collected in such services is also the basis for analytics in demand in many areas related to the analysis of information about the movements of mobile users. Considering the spread (penetration) of smartphones, such analytics is, in fact, an analysis of the movement of users (for example, residents in a city [1], etc.). In the article [2], we used publicly available data to assess the LBS market:

- the volume of the location-based services market was more than $28 billion in 2019, and is expected to grow 6.5 times by 2027;
- search for “proximity services” on Google Scholar shows over 33,000 references in patents since 2020.

The modern LBS architecture is schematically shown in Fig. 1. A user application on a mobile device receives current geo-coordinates and transfers them to the service. In the overwhelming majority of cases, the global positioning system is used to obtain coordinates in one form or another (directly or indirectly). The service, based on the provided coordinates, determines the requested information elements closest to the requestor and/or performs (permits) some actions.

This is a classic example of a client-service system, and location-based services have been around in this form for a long time.

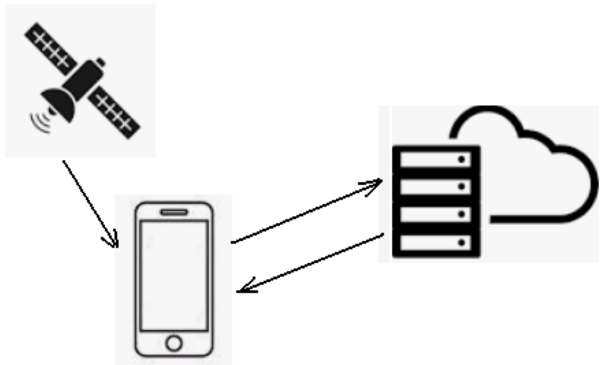

Fig. 1. LBS architecture

Modern developments in this area preserve this architectural model and affect mainly the server-side, in particular, the issues of storing and processing geo-data [3], their presentation, and description [4].

It is a simple model that builds on the ubiquity of smartphones that support global positioning systems (GPS). The client application receives the current coordinates (this is programmatically standardized, for example, W3C) and can provide them to the service. This model was not always like this. For example, back in the early 2000s, a client application could receive location information only from a telecom operator (later - also from a mashup, which, to some extent, emulated the operator's work, providing information about the location of the operator's base stations), but the proliferation of smartphones ultimately reduced it to the use of GPS and a simple client-server system. Various add-ons for the use of GPS, for example, navigation using information about the signal strength of Wi-Fi nodes (Bluetooth Low Energy) [5] are reduced to an alternative method of calculating the geo-coordinates of the client, using known information about the coordinates of basic network nodes and a grid of pre-measured values for signals. This does not change the underlying architecture described above.

In general, LBS applications are classic examples of context-sensitive applications. The context in applications is classically defined as any measurable characteristic that can be added to a location. That is, the current location is always part of the context [6].

At the same time, unlike other contextual data, location information occupies a separate place from the point of view of user privacy [2]. For mobile users, this is, obviously, the privacy of subscribers of telecommunications companies. The

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problem of keeping privacy in geo-positional data is an urgent problem for all mobile subscribers [7], [8]. If we use the above-mentioned method of assessing scientific significance [2], then we can mention, for example, more than 290,000 links since 2017 for the search query “location sharing privacy” at Google Scholar (*scholar.google.com)*.

It should be noted that under the current model of services using location information, there is no way to avoid transmitting location information to the service provider. It is possible, for example, to coarse coordinates in some way (for example, spatial cloaking [9]), but the service provider will still be able to track the use of the service anyway. It is possible to use other protocols for the “safe” exchange of positioning information [10], but they also do not change the basic scheme.

The above-described model, based on the presentation of information about one's own location (real or virtual), remains in operation for social networks, where a special form of check-in was introduced. This mark was introduced as a special message on a social network that contained location information. The purpose of this message was to inform the social network (in fact - the social circle in this network) about its location. The idea is to search for other users (and thus other content) with similar location stamps inside or even outside the social circle. In the future, this scheme can be extended, so that the actions associated with this type of record can be determined by the users themselves [11]. But at the same time, again, the principle is the need to transfer information about the location to a third-party provider, which in this case is the social network itself.

It should be noted, however, that in most LBSs, the actual coordinate information is not needed. There is a small class of services, including those of special use, that explicitly use geo-coordinates. In all other cases, coordinates are used conveniently as clues for data retrieval. This kind of key (coordinates) is obtained on the client-side (using GPS, as mentioned above) and compared with the key of the same type (coordinates) to which the data (service) information is bound. This consideration, in principle, opens up the possibility of replacing geo-coordinates with another metric.

Another consideration is that most of the services provide services (information) in the vicinity of some point. In this case, most often this is the current location of the service client - “find something near me”. Another alternative is some future (virtual or possible) location of the service user (“find something in the city N”).

In this paper, we consider the largest group of services that describe (provide) data (services) in the immediate vicinity of the client (user) of the service. The reason is that it is for proximity-based services that a direct measurement of this very proximity can be offered. This means that instead of the classical scheme, when two pairs of geo-coordinates are measured, the distance between them is calculated, which is compared with a certain threshold: *D* - Euclidean distance, *geom* - coordinates, spatial proximity between two points *G1* and *G2* is defined as

$$D\ (geom\ (G1),\ geom\ (G2)) < \delta_{G1} \qquad (1)$$

where δ_{G1} is some limiting distance that is close from the point of view of *G1*, we will be able to directly check the fulfillment of condition (1) without referring to geo-coordinates.

It was the idea of direct measurement of proximity that formed the basis of the new approach (new architecture) of LBS applications. Instead of using geo-coordinates for the subsequent calculation of spatial proximity, it is proposed to measure this proximity directly. In this case, we are talking specifically about the physical measurement, when the limited propagation of the signal of wireless networks is used as a metric. The availability of a wireless signal, determined by software, will serve as a confirmation of the proximity to the signal source. Accordingly, when describing the services themselves, the identification of wireless network nodes is used instead of coordinates. This model is called the spatial network proximity model [13]. And this article is devoted to the consideration of new (alternative to the representation in Fig. 1) software architectures for the implementation of LBS.

The rest of the article is structured as follows. Section II deals with the network spatial proximity model and its characteristics, which provide new service models. Section III deals with one class of new models of LBS applications, the implementation of which is precisely due to the use of network spatial proximity. Section IV deals with new business models that are made possible (economically viable and profitable) using the proposed software architectures.

II. On spatial network proximity models

Within the framework of this approach, to determine the proximity of mobile devices, it is proposed to use physically limited signal propagation of wireless networks. This measurement is designed to completely exclude work with geo-coordinates (exclude geo-calculations). The signal of wireless networks is a physical characteristic that can be measured by software - this is provided by the appropriate driver.

From a software point of view, discovering a wireless device is getting its advertising information. This is how, for example, searching for neighbors in wireless networks works. Neighbor Search is the definition of all nodes in the network with which a given node can communicate directly. Obviously, nodes must use (transmit) some identification during the discovery process. And the idea of network spatial proximity is precisely to use this identification information (or some add-ons for this information) to transfer user data. This has already been stated in many works, the most recent description is present in [2], therefore, below is a brief description in the form necessary to represent the software architecture.

The limited area of signal propagation of wireless networks is precisely the basis for determining proximity. At the same time, within the framework of the proposed model, no connections are used in any form, and no attempt is made to estimate the location. This is in contrast to, for example, positioning systems that use information about wireless networks. All of them, in one form or another, use information about the preliminary marking of wireless networks signals relative to nodes with known locations [14]. The absence of requirements for location determination allows using not only any existing wireless network nodes (Wi-Fi access points, Bluetooth tags, etc.) to determine network spatial proximity, but also create such nodes specifically for proximity determination tasks. In the latter case, it is possible to arbitrarily set the identification of such nodes (their advertising presentation), and also update it dynamically [15]. For example, a Bluetooth Low Energy device in advertising mode (advertiser) periodically transmits advertising information (Fig. 2) in three presentation channels and listens, waiting for a response from other devices. On the other hand, a device in scanning mode (called a scanner) periodically scans presentation channels (advertising channels) and listens to advertising information from other devices. Promoters differ only in that they can only respond to specific types of advertising packages. The payload in Fig. 2 just allows you to transfer user information in an advertising package without making a connection between devices.

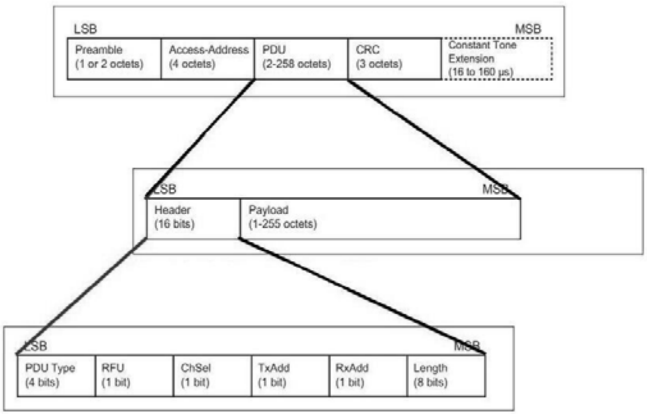

Fig. 2. Bluetooth Promotional Package [16]

As an advertising presentation, the proposed model uses not only its format for Bluetooth LE, but also, for example, the SSID for a Wi-Fi node. It is also broadcast information. And since no connections are assumed for hosts in the used model (architecture used), there are no restrictions for specifying the content of such mailings. The SSID in this model is no longer a name that users have to remember. This information is not intended for end-users, but for applications. This is, in fact, a very important point. This conclusion makes it possible to rely in terms of determining proximity not only on the so-called tags, which were introduced precisely to determine proximity [17], but to use all devices with wireless interfaces. It is technically impossible and economically meaningless to place proximity tags all over the place, whereas in this approach it is possible to dynamically (programmatically) create wireless nodes on mobile devices. As well as to use in this process all existing mobile devices with wireless interfaces: mobile phones, car multimedia panels that support Bluetooth and Wi-Fi, Bluetooth modules of vending machines, etc. The identification of any wireless nodes (networks) can be used to represent “places”.

Thus, in the network spatial proximity model, geo-coordinates are replaced by the identification of wireless network nodes. Accordingly, the proximity check, classically presented as a comparison of coordinates, in the new model is presented as a check of the visibility (availability) of certain nodes of wireless networks. And this check, in turn, consists of fixing the receipt of advertising (identification) of the wireless node. In addition to advertising a wireless node, which fixes the fact of its availability (visibility), its other available characteristics can be taken into account. For example, signal strength (RSSI), direction (for Bluetooth 5), etc. These characteristics can be used in terms to provide services that consider location information as additional terms. The general diagram of the new architecture is shown in Fig. 3.

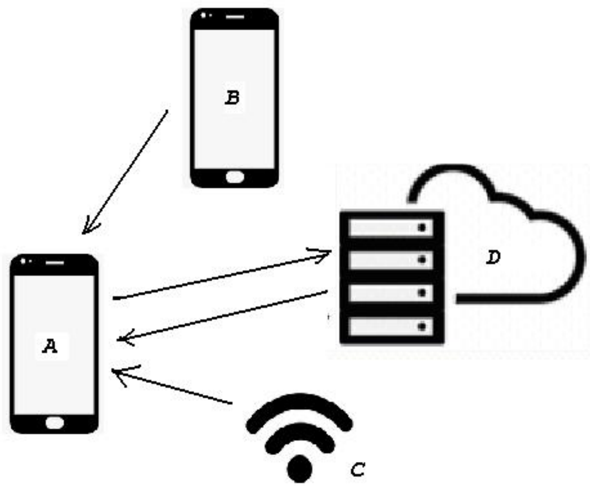

Fig. 3. On the new LBS architecture

User device *A*, instead of requesting geo-coordinates, detects the presence of wireless nodes (*B, C*). Service information can be directly transmitted using customized identification of wireless nodes, or this identification can be used as a key to obtain such information from cloud service *D*. In this case, any devices with corresponding network interfaces can act as wireless nodes used. And the limited scope (accessibility) of such nodes automatically makes the service local (available only in a limited spatial area). This is a very important point for the proposed model - the localization of the service is provided not by checking the boundary conditions, as in geo-grids, but by a physically limited area of signal propagation.

Comparing the proposed model with existing systems for analyzing indoor proximity, it can be noted that the latter are always based on preinstalled BLE tags. In the proposed scheme, all devices can be mobile, as well as the tags themselves can be created programmatically.

The proposed model differs from classical geo-information systems by the complete absence of work with geo-coordinates. As a consequence, this also means that the client does not need to provide his coordinates to the service provider. Instead of the client-server architecture, classical for geo-information services (the client transmits coordinates and receives information), we consider a distributed cyber-physical system (the transmission of the identification of a network node is a physical part of such a system). This is why we are talking about a new architecture for services that use location information.

III. On the one model of network proximity deployment

Formally, the definition of proximity can be represented as some predicate [2]

$$Proximity(WN_1, WN_2, \ldots WN_k) \rightarrow \{Actions, Content\} \quad (2)$$

Where WN_i is the description of the visible (accessible) wireless node. This description includes, as indicated in section II, all available (measurable) characteristics of a particular network node, including information about its advertising presentation. The logical gates in this predicate can describe the conditions imposed on these characteristics. For example, describe possible boundaries for the strength of the RSSI signal, or simply check the availability of a node with a given advertising presentation [2]:

$$WN.RSSI < -90$$
$$\exists WN.SSID = "Cafe"$$

The predicate itself is formed as a logical combination (AND, OR, NOT) of such elements, which is used to check the proximity to the specified reference nodes (node) of the wireless network.

It is the computation of such predicates that is the test of network proximity. The very definition of available network nodes (network fingerprints) can be performed directly in the client mobile application. Verification of the location-specific terms of service can then be performed either directly on the client-side, or on the service-side where the client contacts by transmitting an available network fingerprint (i.e., data about the available network environment).

A set of these kinds of rules can also underlie a fuzzy logic system for choosing rules from several suitable ones [15]. This approach has been used in many applications based on our early work. Typical use can be represented, for example, as follows [18]. A retail retailer's mobile application checks information about available (visible) network nodes, which makes it possible to understand whether a mobile user is currently in one of the shopping malls (as well as in which one), which may be the basis for issuing special offers (discounts, etc.) (halls), or the mobile application is currently running outside the walls of the shopping complex. Network information can replace location information in so-called super applications [19]. These are mobile applications that capture all user actions on mobile devices. Using information about the network environment is the most affordable way to customize super applications, which will work indoors, when GPS is not available.

In this paper, we consider a model (architecture) that describes the setting of conditions for the provision of LBS without explicitly specifying the available network environment. The idea is to place one (several) network nodes (also static or dynamic) that are uniquely identifiable within a certain area at the place of service provision, so that they will "see" the same network environment as the client device. For example, in Fig. 4, some user's device *B* "sees" the same network environment (in this case, some Wi-Fi access point) as the dedicated device *A*.

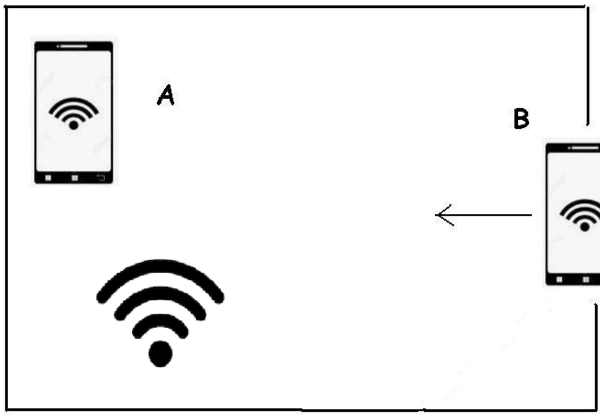

Fig. 4. General network environment

Accordingly, the condition for providing a service (performing actions) can be represented (described) as a "common network environment with some dedicated device (s)". What is it for? In this form of setting conditions (and these conditions still describe some location, that is, they replace geo-coordinates) there is no explicit setting of information about the network environment. This environment can change and there is no need to update client applications with these changes. It is only necessary that the selected device (s) be present in the changing environment.

For example, refer to the above-mentioned example when network proximity is used to determine the current presence of a mobile user in a location. Suppose the LBS app needs to provide coupon codes in two different locations. This leads to the need to describe the network environment in two different rooms (that is, two network fingerprints). As well as updating this information when something changes. In the proposed model, it is enough to have a reference device with the same identification in both rooms and to set one single rule - a common network environment with a dedicated reference device. At the same time, such a service can be easily extended to any room (site), simply by placing there a supporting device with the same identification. Moreover, such a device plays the role of a dynamic switch for the service. Moreover, such a switch is obviously mobile. In particular, it can be placed on a moving object. The device can appear in a certain area, thereby turning on the corresponding service, or leave this area, turning off this service. Such "movement" can also be simply implemented by turning on and off the collection of information about the network environment on the reference device itself. Its appearance in a certain area is the activation of the collection of network information, while the stop of the collection of network information corresponds to the stop of the provision of the service.

Accordingly, the operation of such an architecture is based on the comparison of the network environment (fingerprint) of the user device and the reference device

$Match(F_1, F_2)$ *where* F_1 *and* F_2 – are network fingerprints

The approaches to the comparison of network fingerprints themselves are sufficiently developed, for example, in works on Wi-Fi navigation [20] and can be used here. For example, the similarity of two measurement vectors A and B can be determined using the Jaccard coefficient

$$J(A,B) = \frac{|A \cap B|}{|A \cup B|} = \frac{|A \cap B|}{|A| + |B| - |A \cap B|}.$$

or Tanimoto

$$f(A,B) = \frac{A \cdot B}{|A|^2 + |B|^2 - A \cdot B}$$

The measured vectors here are lists of available (visible) network nodes. Comparison of fingerprints is shown in Fig. 5.

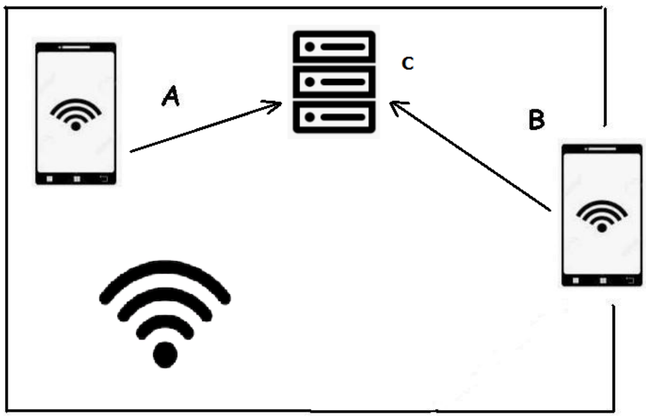

Fig. 5. Comparing fingerprints

The user device B (application on this device) transmits to the application server C current (instant) information about its network environment and the identification of the reference device A with which (with the network environment of which) it is necessary to compare. In fact, it is the identification of the reference device (s) that defines a specific service (LBS application).

Based on the availability of the application server, an arbitrary ID can be used as the identification of the reference devices, which will help the application server to select from the received network fingerprints those that relate specifically to the reference device (s). Technically, it could just be a GUID, advertising representation of a network node, device MAC address, IMEI, etc.

What can act as a support device? The simplest case is a mobile phone, the installed application of which simply transmits information about the network environment to the application server. We have repeatedly used this kind of model in projects using the network proximity model in wireless networks. Examples of such systems can be found in the previously cited works [2, 13, 15]. For example, a loyalty system in retail, where proximity (and, accordingly, location) was determined in relation to a dynamic (software-created) wireless node on the seller's mobile phone. Accordingly, this leads to a two-tier model of LBS applications: there is the actual LBS provider (provider), and there is the one who provides it with infrastructure support. The infrastructure operator provides its user (LBS provider) with mobile tracking devices (option - obtains a list of tracking devices from the LBS provider). Further, the LBS provider is already providing these services to its mobile subscribers, who are close to the reference mobile devices.

Practical example: infrastructure operator - telecommunications operator. LBS provider is a shopping mall. The provider has a mobile application for its users (visitors) with a loyalty program. The LBS itself is, for example, some special offers for visitors to the shopping mall. The provider receives a set of devices from the operator (option - informs about the selected own devices), relative to which the proximity of end-user devices will be determined. The selected (reference) devices are placed by the LBS provider in the required ones (required at the moment, this can be arbitrarily changed at any time). In a mobile application, it is possible to determine the current position of the user with respect to these reference nodes (the end user's mobile phone "sees" the same network environment as some reference device). And put the network spatial proximity thus defined as the basis for the provision of location-dependent services.

The actual determination (estimation) of the position with the help of reference devices makes it possible to provide services in this way in several spatially separated places. The rules for the provision of services do not depend on geo-coordinates, but on the presence of reference devices. For example, a trading company can provide the same services to mobile users of its application without changing the rules for their provision (without editing these rules for each new trading platform).

The lack of direct binding to geo-coordinates (which, of course, are always publicly available) makes it possible to restrict access to LBS (for example, providing it only to users of specific mobile applications).

The reference device itself can also define the network environment. The reference device may itself be a wireless network node to which proximity is determined.

We also note that in this form, the service for supporting the network proximity model based on 5G D2D [21], which we presented in our works as a solution for 5G, becomes just an example of presenting a general model based on the mutual proximity of mobile devices.

IV. On the New Business Models for LBS

In this section, we would like to highlight the new business models that are emerging within the proposed LBS architecture.

The proposed LBS model has the following sides:

- The operator (application provider) of proximity determination.
- The provider of location-specific content (service-provider). It could be an application provider too. The same participant can act as both the operator and the content provider.

- Service users (customers) who operate with mobile devices (supporting devices)
- End-users (mobile clients)

In comparison with the classical scheme, an operator (provider) has appeared that supports the definition of proximity. The application server in Fig. 5 is the main component of this provider. Mobile clients transmit information about their network environment to this provider so that it can be compared with the same information received from reference devices. The information about the network environment in this case replaces the information about the location. In this case, the location data is completely missing, since there is no information about the location of the network nodes. They can actually be created dynamically (programmatically), and their true location is unknown.

At the same time, since we are talking about mobile clients, there is always a telecommunications operator that, according to the license, tracks (can track) the location of its customers. It is logical in this case to compare the network environment also on the operator's side. In this case, there is no transfer of even an analogue of the location information to third parties. Only the mobile client and the operator are involved in the operation. The 5G D2D example mentioned above also fits into this scheme, since it is precisely the operator's technology. Mobile phones that will be used as reference devices can also be provided by the operator.

Accordingly, this scheme involves:

- Telecommunication operator
- Service customer operating with several mobile devices (support devices)
- End-users (mobile clients)

In this case, the actual data for the LBS may be outside the operator's area of responsibility. As described in [21], this can be an external database.

This description means that telecommunications operators can again become participants in the LBS market. LBS applications, as services, were originally operator-based, the location of a mobile device could only be determined by operator data. Further, the development (penetration) of smartphones and the standardization of access to GPS [22] led to the fact that services began to be implemented completely without operators [23, 24]. The addition of geo-positional information to social media completed this process.

The proposed architecture naturally returns operators to the LBS implementation scheme. At the same time, the proposed architecture, as described above, covers the use of 5G.

By controlling the placement of the backbone nodes, a telecommunications operator in this model can provide the same services (the same terms of service) at any point of its presence.

Also, within the framework of such a business model, the service provider (that is, the operator) can, if necessary, introduce various forms of payment for such a service. evaluate your work in a variety of ways. This may be some kind of fixed (flat) price, the price may depend on the number of devices, etc. Since in such a model all checks for the provision of services go through the provider, billing schemes (tariffs) are possible, taking into account the number of calls, their intensity as well as query execution time.

Thus, not only a new architecture for LBS applications is presented, but also new business models for service providers. The latter aspect has also attracted more and more attention recently [25, 26].

Note also that the operator (provider of proximity services) still has all the possibilities to launch universal services based on its own reference devices. For example, one of the service models that uses customization of the advertising presentation of a wireless node and tested by us in our previous works on network proximity [15]. We are talking about broadcasting any text information. In this case, the information is "transmitted" as an advertising presentation of the site. Recipients of this data see it simply as a representation of existing nearby wireless nodes. To transmit long texts, we can split them into shorter packets (strings), the last character of which indicates the need to concatenate the next packet upon receipt. In this way, the recipient can assemble the individual parts into a complete text.

There are several important points to note. In such services, there is no need to organize the coordinated work of the transmitter and recipients of the information. It is enough just to repeat the entire text several times. Then, any receiver in the middle of a transmission (which appeared next to the transmitter after the broadcast started) would receive and display only a portion of the information in the first receive cycle, and then receive and display all of the text. This will be a complete imitation of the information tape on the scoreboard.

Secondly, there can be multiple transmitters. The receivers will distinguish them by the addresses that are present in the advertising packages.

In addition, it is obvious that we can support the presentation of some structured information in the text. For example, when displaying the received text, it automatically highlights phone numbers, e-mail addresses, etc. This will allow us to display the data most convenient for later use (the ability to directly call the number, etc.). At the same time, the application for reading such data can be standard (the same for all participants). In our early work, we described this as a physical browser.

This scheme eliminates the need for separate storage of information about geo-referenced content. All necessary information will be directly broadcast by the reference devices. And the recipients of such data can be all mobile clients who find themselves in the vicinity of the reference device. Moreover, unlike mailings (SMS, push), this scheme describes a pull model. Only those who are clearly interested in it (launched the corresponding application) will read such information.

From the point of view of the business model, this option opens up new forms of submission (presentation) of advertising content, which can be dynamic (support devices can, of course, change their mailings) and localized (available only in a limited area).

V. Conclusion

This article introduces the new software architecture for services using location information. The proposed scheme is based on the use of architectural solutions of the network spatial proximity model. The presented model compares the characteristics of the network environment of user (client) devices and some dedicated mobile devices that play the role of mobile tags. Accordingly, the proximity of the client mobile device and some reference device is the basis for the provision of a service, which, therefore, does not use geo-computing in any form.

The proposed scheme opens up new opportunities for building service business models using location information. First of all, this is a change in the role of telecommunications operators in terms of providing services using location. In new business models, it is the telecommunications operator that plays the role of the service provider. The LBS scheme is now fully decentralized. Clients determine their location on their own, operators are not represented in LBS business models. In the proposed scheme, the mobile operator receives the natural role of a provider for calculating proximity (in fact, a provider for an alternative form of geo-computing). At the same time, the operator has every opportunity to build a mature payment system for the provided services.

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