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Mobile Phone Sensing as a Service: Business Model and Use Cases

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Abstract --- With the ubiquity and ever-increasing capabilities of mobile devices and the integration of more and more sensors in them, such devices now have the potential to act not only as personal communication and computing platforms but also as sensing platforms. Mobile phone sensing is a complementary and radically different sensing approach in which smartphones fulfill the sensing role (instead of dedicated wireless sensor networks), by acting as super sensor nodes and gateways. There are several motivations behind the mobile phone sensing approach, such as: Increased sensing coverage area due to phones' mobility; enhanced information processing/validation capabilities; the addition of a social dimension to sensing, and the easy on-demand deployment of new sensors. In this paper, we propose a new business model for mobile phone sensing environments, and elaborate a new identification and charging scheme to support its operation. A number of use cases related to mobile phone sensing are also presented. The proposed business model promotes the idea of Mobile Sensing as a Service, in which a number of mobile sensing terminal operators offer their sensed data as a service to the network operator, which can then disseminate it to interested entities (e.g. specific users, communities, and network nodes).

I. INTRODUCTION

The concepts of context and context-awareness [1,2] have emerged in the field of pervasive computing [3] that aims at achieving rich, intuitive, and natural interactions between humans and computing devices surrounding them. While context implies situational information related to different entities (e.g. a user's location, a device's battery level, or a network's available capacity), context-awareness signifies the ability to use this contextual information in support to operations and decision making and for the provision of relevant services to the user. As a main value preposition, context-awareness is considered to enhance users' experience and is seen as an enabler to adaptability and service personalization. Typically, contextual information is collected using dedicated sensing platforms in the form of densely deployed, energy efficient Wireless sensor networks (WSNs) [4]. Despite the advances in the area of WSNs, such platforms still face important challenges and suffer from several limitations, such as: limited processing and communication capabilities, limited energy source (non-rechargeable batteries), static deployment, and restricted sensing coverage area. Those limitations have hindered the large scale commercial deployment of WSNs, which are currently only deployed on a small scale for highly specialized niche areas (e.g. environment monitoring and building automation).

With the ubiquity and ever-increasing capabilities of mobile devices, a radically different and complementary sensing approach has been recently proposed: mobile and participatory sensing [5, 6]. In such approach, instead of deploying dedicated sensing platforms, mobile phones (smartphones) fulfill the sensing role, by acting as super sensor nodes and gateways. In contrast to traditional sensor platforms, mobile phones have been constantly improving in performance with respect to CPU and memory resources, as well as communication capabilities. Most notably, the sensors integrated in mobile phones are getting more and more sophisticated and can be used to collect and disseminate a variety of contextual information.

So far, mobile phone sensing applications largely focus on the utilization of the sensed information by local mobile applications (running on the phone), or by server-side applications residing on servers in the Internet (e.g. social and urban sensing applications) [7, 8]. While these applications have their merit, they all rely on proprietary context acquisition and management functionality that has to be developed each time from scratch, and cannot be reused by new applications. Thus, they suffer from the lack of unified and reusable infrastructure for mobile sensing data acquisition and management.

In this work, we propose the concept of Mobile Sensing as a Service (MSaaS), in which we perceive mobile devices as data collectors, and mobile device users as willingly participating in the sensing process and even augmenting the sensed data with their input/perception (i.e. human acting as an additional sensor with pre-processing and validation capabilities). After some initial processing on the mobile terminal, the user can publish (and get paid for the publication of) the refined data to the mobile communication network, in which the information will be centrally managed and disseminated to interested entities. Examples of such entities could be: the user himself (e.g. for interest-based services); other users (e.g. family members, friends, and care takers); the community (e.g. for neighborhood or traffic watch); or the network operator (e.g. of enhanced QoS management or mobility management).

In this paper, we propose a novel business model for mobile phone sensing. In this model, we define the different business roles and the interactions needed to realize the concept of Mobile Sensing as a Service. Identification and charging schemes are also proposed as support functions, and different motivating scenarios for mobile sensing environments are presented.

The rest of the paper is organized as follows: Section 2 provides an overview about the mobile sensing concept, including its related challenges and opportunities, as well as a description of some motivating scenarios and use cases of utilization. In Section 3, the proposed business model and its related identification and charging schemes are elaborated. We end the paper with our conclusions and highlight future work.

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II. FROM TRADITIONAL SENSING TO MOBILE PHONE SENSING: OPPORTUNITIES, CHALLENGES, AND MOTIVATING SCENARIOS

In this section, we compare the traditional sensing approach to the mobile phone sensing approach, in order to highlight the opportunities and challenges introduced by this new sensing approach. We end the section with a description of some scenarios that could be enabled in a mobile sensing environment.

2.1 The Traditional Sensing Approach: Limitations and Challenges

Wireless sensor networks consist of a set of distributed sensor nodes that collaborate to monitor physical and environmental conditions [4]. A typical WSN architecture encompasses three main types of nodes: sensors performing the actual sensing; gateways acting as link between the WSN and the outside world by performing the needed mapping and protocol conversions; and sinks collecting data from the sensors and interacting with applications via gateways. Nowadays, WSNs are used in several domains [9] ranging from disaster relief operations where nodes are deployed randomly to collect information, to biodiversity mapping and intelligent buildings where a regular deployment is performed with well-studied localization of the different sensor nodes.

Despite their usefulness and potential application areas, WSNs still suffer from many limitations - most of them being directly linked to the nature of sensor nodes. Among those limitations, we mention:

- Power Restriction: With the absence of wires, sensor nodes do not have a constant power supply and not many power options exist. They are typically battery-driven which means a periodic replacement of batteries is required - a hard task especially for sensors deployed randomly or those deployed in hostile environments.
- Limited computational capabilities: Knowing that the more the sensor is running for detecting or processing information, the more the battery is drained, designers tried to limit the computational capabilities of sensors. Although it is acknowledged that sensors are not expected to have the computing power of workstations, constraining their computational capabilities limits their use and raises other problems such as adequate security level of the WSN and processing the collected data.
- Storage restriction: as a direct consequence of their limited capabilities and size, sensor nodes have also limited capability for storage. Communication needs to be established with the sink to send the collected information.

Obviously, all these constraints bring many challenges to researchers. First, even with the current rising need for collecting more contextual information, sensors are not massively deployed in the environment. Their limited lifetime requires their replacement or retirement causing a disposal problem. In addition, their high need for maintenance prevents from their large scale commercial deployment support. Until today, they are still perceived as domain and application oriented and they are used in very specific niche areas like environment monitoring, pollution monitoring, building automation, and the oil industry. Second, WSNs suffer from well-known security issues that are becoming a key concern for WSN protocol designers [10]. Since sensor nodes are usually severely resources constrained, asymmetric cryptography is too often expensive for many applications, driving the shift to use symmetric key cryptography. However, the storage restriction makes centralized keying techniques impossible. As a result, WSNs are vulnerable to many attacks; a major problem when it comes to privacy-critical applications. To overcome these problems and ease the maintenance of sensor nodes, researchers have been trying to constantly improve the hardware capabilities of sensors on the one hand and to have a more controlled deployment on the other hand.

More recently, with the widespread of smartphones and tablets, new researches focus on the potential of using them as mobile super-sensors that can not only complement traditional sensing approaches but also substitute the use of traditional sensors in many domains like community sensing.

2.2 The Mobile Phone Sensing Approach: Opportunities and Challenges

Prior the introduction of the iPhone in the market (in 2007), few phones were sensor-enabled or offered means to access sensory information collected by them. However, with the introduction of smartphones, most of todays' phones come equipped with many built-in sensors like cameras, GPS, microphones, gyroscopes, compasses, accelerometers, proximity sensors, and ambient light sensors. Smartphones can also be easily combined with many external sensors like Bluetooth-enabled glucometer, electrocardiogram, and electroencephalogram. In addition, most of the modern mobile operating systems offer open programming interfaces enabling access to the sensory data. The integration of sensors in the mobile phone opens the door to a new use of phones as sensing devices, namely mobile phone sensing. A variety of application domains such as homecare, healthcare, social networking, safety environment monitoring, E-commerce, and traffic road monitoring, target the use of phones as sensing devices. This is mainly because of the advantages that these super sensing devices offer compared to traditional sensors.

Table I shows a comparison between mobile phones as sensors and traditional sensors. First, mobiles phones have the advantage of acting not only as sensing nodes but also as sinks and actuators. Furthermore, they are embedded with many sensors and can collect different types of information at a time. Third, they have more computation and communication capabilities than traditional sensors. Moreover, mobile phone sensors may have better coverage area and can help increase the scale of the sensing because of their mobility. In case of participatory sensing, the user can have an additional input to the collected information regarding what to send and when to send. It also can be selective to whom to send in the case of social sensing. Finally, many actors can benefit from this form of sensing, including: the user himself, a community, a third party but also the network itself, which was never the case with traditional sensing.

TABLE I
COMPARISON BETWEEN TRADITIONAL SENSORS AND MOBILE PHONES AS SENSORS

Property	Mobile Phone as sensors	Traditional Sensors
Computational capabilities	High	Very limited
Storage	High storage capabilities	Very Limited
Power	Rechargeable	Battery-powered; needs maintenance
Connectivity	Occasionaly disconnected; Support wide range of technologies	Tied to specific technology
System Action	Can make decisions	No decision making
Data	Raw or Processed	Raw
Mobility	Unpredicatable mobility	Regular/ Random
Security	Security protocol for mobile phones	Limited
Role in Sensor Network	Sensing node, sink, actuator	Sensing node
Ownership	User	Company

Despite its potential, mobile phone sensing introduces new challenges, namely:

- In order to provide context aware services to mobile users, there must be specific entities which have to continuously monitor different types of contexts and capture their changes in time [11].
- A mobile phone is a personal device. On the one hand, it is difficult to anticipate in advance its mobility and its availability. This will affect the quality of the captured data. Phones may be exposed to the event for too short a period of time [7, 12]. On the other hand, devices are no more managed by a single authority.
- While mobile phone continue to offer more computation, memory, storage, and sensing capabilities, the phone is still a resource-limited device [7] and the sensing task should not interfere with the primarily role of a mobile phone, which is communication.
- More importantly, traditional business models do not take into consideration the fact that the user may act as a data producer. Inverting the role between the provider and the consumer needs to be integrated in the business model.

2.3 Mobile Phone Sensing Use Cases

In the coming section, we describe three use cases that show the potential that mobile phone sensing can offer to different beneficiaries: 1) the mobile phone user; 2) a community of users; and 3) the network operator.

A. Community-Centric Use Case

Nowadays, there is a growing need for answering requests with very specific constraints, more specifically real time context aware constraints. In Nordic countries where it snows a lot, having real-time information about the roads clearing off is critical for traffic management. On a snowy day, in a given traffic light, the driver may want to know if the snow is cleared off from nearby roads. This request cannot be answered without the collection of real-time contextual data. Even if traffic sensing systems are growing in popularity in major cities via the use of fixed sensors deployed on major highways, these systems come with a significant expense and there is still little coverage of side streets - a drawback that can be addressed using mobile phone based community sensing [13]. Community sensing offers a great opportunity to fuse information from populations of privately-held sensors (drivers in our example) to create useful information and share it. Using the GPS location of drivers and according to the real time data collected from community members' phones, the information about the roads cleared off could be displayed to the driver, helping him/her to choose the best path and avoid congestion. This information would be updated continuously based on the change of the collected data and the geo-location of the driver. Other potential use cases could include interest-based services requiring the collection of real-time contextual data using collaborative social sensing. Examples include: searching for a quite coffee shop or a cinema without children.

B. User-Centric Use Case

Call handover is a well know concept in mobile networks, aiming at seamlessly transferring the control of a call session between different towers, as the user moves between mobile cells. Currently, handover is taking place without considering the context of the user, such as the battery status of the user's device, the user's geo-location and mobility pattern. Current networks use the same handover mechanism for each and every user, which is not necessarily the best approach. Let us consider the case of a driver whose phone has a low battery level. As demonstrated in [14], the received signal strength has a high influence on the time needed for sending a message and therefore impacts the energy consumption. In an ideal scenario, knowing the GPS location of the user as well as his speed would help to perform the handover before the fading of the signal and avoid draining the battery to prevent the disconnection of the phone. Again, drivers' phone, using the built-in sensors, can sense and provide such information and play the role of data collector.

C. Network-Centric Use Case

Having a context aware handover mechanism does not serve the users' benefits only but also helps the network provider in achieving better mobility management. It is well admitted that the mobility of the vast majority of mobile phone users adheres to specific patterns. Monitoring such patterns may help the network provider in many ways: 1) It can limit the numbers of handover since it can predict the mobility of the user 2) It may help in balancing the load among towers more efficiently, and finally 3) Can be used to develop some prediction mechanisms to serve the incoming sessions with respect to current load of towers.

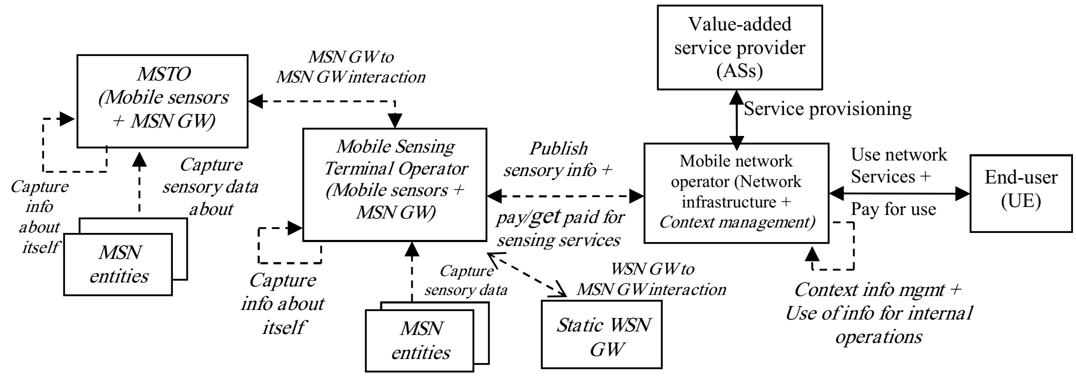

Figure 1. Proposed business model for mobile phone sensing as a service

Other areas in which the network can leverage mobile sensing data are: enhanced QoS management (e.g. giving the user's session specific priority and QoS guarantees, based on the user's situation and location), automatic media adaptation (e.g. using specific media types and codecs based on the mobile device resource and connectivity levels), and enhanced security support (e.g. offering different levels of security depending on the user's geo-location).

III. BUSINESS MODELING AND SUPPORT FUNCTIONS

In this section, we discuss several business issues related the realization of the Mobile sensing as a service concept, namely: the business model and the identification and charging schemes proposed.

3.1 Proposed Business Model

Business models are very important for the practical deployment of solutions in commercial environments, and are usually used as the starting point for standardization. A business model describes the different parties (or business roles) involved in service provisioning and their relationships/interactions. Several business models have been proposed for the telecommunication domain, such as the TINA and the Parlay business models, while few others have been envisaged for the Internet domain, including the basic web service and the composed web service business models. Reference [15] can be consulted for an overview of these business models.

In 3G and 4G networking environments (which are currently deployed), the used business model defines three main business roles: the end-user; the service provider; and the network operator. The end-user is an entity that has a service usage agreement with the network operator and which owns the user equipment (UE) needed to invoke/use services. The service provider owns the application servers (ASs) hosting and executing value-added services; while the network operator owns the network infrastructure on which ASs rely for session control and traffic transportation.

To enable the realization of the mobile phone sensing as a service, we propose the extension of the basic 3G/4G business model with new roles and interactions. **Figure 1** illustrates the proposed model, in which the new roles/interactions are shown in italics and dotted lines.

Two new roles are proposed in our business model: Mobile Sensing Network (MSN) entities and Mobile Sensing Terminal Operator (MSTO). The MSN entities are the entities whose information is being captured by the sensor-embedded mobile terminals and conveyed to the 3G/4G network. Those entities could be associated with a specific user (user's personal belongings, home, or family members), or associated with a community of users (e.g. hospitals, roads, trees, and buildings). The MSTO is a user who is equipped with a mobile phone, and uses it to capture contextual information about MSN entities. After pre-processing the captured information, the MSTO publishes it (and possibly gets paid for its publication) to the mobile network, where it is centrally managed and disseminated to entities of interest. The mobile sensing terminal can be considered as a special type of UE, which is embedded with local sensors and augmented with MSN gateway functionality needed for the processing, formatting, and publication of the information in the network. It is in fact a personal communication device and an integrated sensing platform, all in one node. The MSTO may be a regular user who is sensing data in an opportunistic or participatory mode, or could be a person employed by the municipality to sense and capture information about the community-managed objects and places. In the case of participatory sensing, the MSTO may augment the raw sensed data with his/her own perception and input, thus acting as human sensor. For instance, the MSTO may do some pre-processing and validation of the sensed information (e.g. choosing which relevant data to send and when to send it) and generate data with different level of granularity (e.g. publishing information about a quiet place without kids implies collecting data from embedded noise sensors and augmenting it with the user perception about the type of people occupying the place). Another dimension that may be added in the case of participatory sensing is the social dimension (i.e. the MSTO choosing to share the sensed data with people with common interests). It should be noted that the MST may capture sensory data about itself, its user and its surrounding environment, as well as information about other users, objects, or places. Furthermore, MSN gateway to MSN gateway interaction may be used for the direct sharing of sensory data between MSTOs. In the case of hybrid systems, relying on static WSNs and mobile phone sensing, the interaction of MSN gateways with WSN gateways may be useful for the collection of additional sensory data (captured by static sensors) by the mobile sensing terminal.

Finally, to account for the interaction of the communication network with MSTs supplying it with sensory data, the function of the 3G/4G network infrastructure (owned by the network operator) is enhanced to include: the management of the mobile sensing information; the usage of this information for internal network operations; and the dissemination of this information to other interested entities (e.g. users or communities).

3.2 Identification Scheme

The ability to identity users/entities accessing and using the network resources is central to any telecommunication system, as it allows accountability for the utilization of network resources. In the mobile phone sensing environment, to enable MSTOs to publish contextual information about MSN entities in the network, there is a need to identify those MSN entities in the 3G/4G world, and charge for their information exchange related interactions (e.g. information publication and subscription related interactions). To solve this issue, we propose a hierarchical identification scheme that is depicted in figures 2a and 2b.

Figure 2a illustrates the identification scheme proposed for the case of official community representatives, who are employed by the municipality to sense information about its managed objects and places. In that case, the municipality acts as network subscriber and is assigned a corporate account. This account is associated with a number of SIM cards, which are assigned to the official representatives. Each SIM card stores a unique private community ID (mainly used for authentication purposes), a public community representative ID (used during the network registration phase) and a set of dependent and implicitly registered MSN entities IDs (used for information exchange related interactions). Figure 3 illustrates a possible SIP URI scheme that can be used for the representation of public community representative and public dependent identities. As for private identities, which are used for identification and authentication purposes only and are hidden from the user, they take the form of network access identifiers such as username@operator.com.

Figure 2b illustrates the identification scheme proposed for the case of regular users who are willingly capturing contextual information about surrounding MSN entities, using their MSTs, and publishing that information to the network. In that case, the user acts as a regular network subscriber and is assigned a SIM card storing his private user ID, as well as a set of public IDs and associated dependent MSN entities IDs. Three different public identities can be used by the MSTO, depending on the role he/she is playing and the beneficiary from the sensed information. These identities are: 1) Public user ID (if user himself is beneficiary of sensed data); 2) Public community representative ID (if a group or community of users are benefiting from this information that is collected in a collaborative manner); and 3) Public network operator representative ID (if the network operator is the one benefiting for the sensed/published data for the enhancement for the network's operations and services).

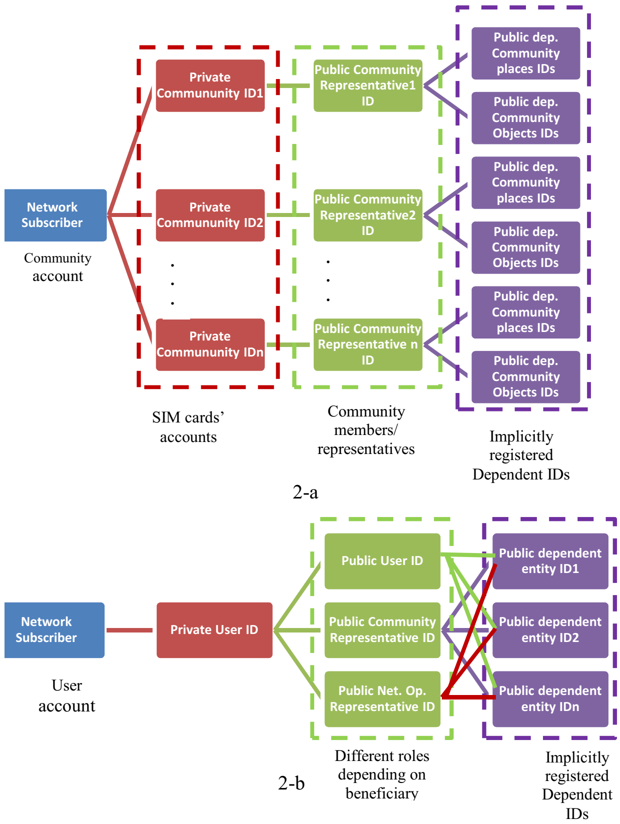

Figure 2. Hierarchical Identification Schemes: a) Official community representative MSTO case; b) Regular user MSTO case

Public community Representative identity:
UserName.CommunityName.City.Country@operator.com
Public dependent entity identity:
EntityID.UserName.CommunityName.City.Country@operator.com

Examples:
- Representative ID:
NURSE-MarthaDavid. RoyalVicHospitalCommunity.Montreal.Canada@operator.com

- Hospital room status:
ER201.AdamJhones.RoyalVicHospitalCommunity.Montreal.Canada@operator.com
- Cinema Chair status:
CinemaChair100.AdamJhones.GuzzoCinemaCommunity.Laval.Canada@operator.com

Figure 3. SIP URI scheme for public community representative identities and dependent MSN entities identities

3.3 Charging Model

In this work, we promote the idea of Sensing as a Service, in which a set of MSTOs offer processed mobile phone sensed data as a service. To realize this concept, we envision four different charging scenarios that are summarized as follows:

- **MSTO as self-representative:** This is the case where the MSTO is the one benefiting from the sensed data and pays for the usage of this information (e.g. user sensing his geo-location and publishing it to benefit from location-based services). It should be noted that if the sensed information is used locally by an application running on the phone, then no charges would be incurred. However, if the information is used by a networked application that accesses it through the network, then the user would have to pay for publishing the information.
- **MSTO as peer-representative:** This is the case where a user senses data for other users (e.g. sensing traffic road conditions and sending this information to friends or relatives). In that case, if the information is exchanged through the network, then the beneficiary users would have to pay for information access and the profit is shared between the network operator and the MSTO who sensed the data (i.e. the sensing node would get paid for its sensing services in that case). The payment could be in the form of money credit (added to the user's account) or service credit (e.g. free minutes). If the information is exchanged in peer-to-peer mode between users, then no charging occurs in that case.
- **MSTO as network operator representative:** This is the case where the user senses data from which the network operator benefits to enhance its network's operation (e.g. information about users' mobility patterns, or perceived QoS). In that case, the network acts as information consumer and the user acts as information producer (inversion of roles). In that scenario, the MSTO gets paid by the network operator for his sensing services using money or service credits.
- **MSTO as community-representative:** This case has two variants: 1) the case where the MSTO is officially employed by the municipality to sense data about its managed objects and places, and 2) the case where a group of MSTOs collaborate to sense data for the benefit of their community (e.g. neighborhood watch). In the first variant, since the municipality is the beneficiary of the sensed data, its administration would pay for information access from the network, and the sensing MSTO would get paid for his/her sensing services. In the second variant, charges for information access are split among the community members, since they collaboratively benefit from the sensed information. Support for dynamic membership in groups/communities would be needed in that case.

IV. Conclusions And Future Work

In this paper, we have proposed the idea of mobile sensing as a service, in which a group of mobile sensing terminal operators (MSTOs), equipped with sensor-enabled terminals with information processing, and dissemination capabilities, are willingly sensing contextual information about different entities, and offering the sensed data as a service to the network operator. To enable the realization of this concept, we have proposed a novel business model for mobile phone sensing environments and elaborated an identification and charging scheme to support its operation.

As future work, we plan to work on the definition of an expressive information model enabling the representation of a variety of sensed data, as well as the design of an efficient and scalable architecture for the integration of mobile phone sensing capabilities in communication networks.

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