
Preserving patients' privacy in health scenarios through a multicontext-aware system

Alberto Huertas Celdrán · Manuel Gil Pérez · Félix J. García Clemente · Gregorio Martínez Pérez

Abstract The Big Data age is characterized by the explosive increase of data managed by electronic systems. Healthcare Information Management systems are aware to this situation having to adapt services and procedures. This, along with the fact that the proliferation of mobile devices and communications has also promoted the use of context-aware services ubiquitously accessible, means that protecting the privacy of the patients' information is an even greater challenge. To address this issue, a mechanism that allows patients to manage and control their private information is required. We propose the preservation of patients' privacy in a health scenario through a multicontext-aware system called h-MAS (health-related Multicontext-Aware System). h-MAS is a privacy-preserving and context-aware solution for health scenarios with the aim of managing the privacy of the users' information in both intra- and inter-context scenarios. In a health scenario, h-MAS suggests a pool of privacy policies to users, who are aware of the health context in which they are located. Users can update the policies according to their interests. These policies protect the privacy of the users' health records, locations, as well as context-aware information being accessed by third parties without their consent. The information on patients and the health context is managed through semantic web techniques, which provide a common infrastructure that makes it

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possible to represent, process, and share information between independent systems more easily.

Keywords Context-awareness · location · eHealth · privacy-preserving · policy

1 Introduction

Historically, Healthcare Information Management systems [1] have generated large volumes of data related to Electronic Health Record (EHR) [2]. These massive quantities of data, known as *Big Data*, have influenced critical changes in the patient information management processes. Adding to this fact that current mobile communications have led to the emergence of new ubiquitously accessible services, the management of the patients' location and context-aware information is an even greater challenge.

In this sense, high-level healthcare applications can be further developed by integrating mobile device telecommunication functions with the users' context [3]. Context is a concept that combines the information about the environment where users are, their location, their identities, the identity of nearby people and objects, and any changes in the previous terms [4]. These context-aware applications can be useful and helpful in managing the patients' information, with concern for patients' privacy and how personal information, location, and context information are revealed. An example of these services could be a hospital context, which has a service to share medical information (e.g., the EHR of a patient) between patients and doctors that protects the privacy of the patients' information.

1.1 Motivation

Preserving the health information taking into account the context in which patients are located is an open challenge. We can find in the literature a depth survey of e-Health systems oriented to cloud computing that analyzes a large number of solutions by considering different topics [5]. Additionally, a recent work is proposed in [6], where current security and privacy challenges are pointed out from different perspectives oriented to many diverse scenarios. Focusing on non-cryptographic approaches, several solutions have been proposed in order to preserve and exchange health information in a privacy-preserving way [7,8,9]. These solutions protect the health information without considering the location of users neither their contexts. In this sense, several privacy-preserving and context-aware solutions have been proposed taking into account the location of users in order to protect the personal and contextual information [10,11,12]. However, these solutions are not oriented to eHealth environments and they do not consider the protection of medical information [13], or they do not manage the mobility of users between different contexts [14]. The main characteristics of the presented solutions are illustrated in Table 1.

We believe that patients of context-aware and health-oriented systems should be able to manage dynamically the privacy of their medical records, personal information, locations, and information related to the environment or context in which they are located (intra-context scenario). This is an even more complex process when users move between several contexts, and there is an exchange of information

between them (inter-context scenario). Following the previous example, when the patient leaves the hospital, he goes to the pharmacy in order to buy the prescribed medicines. This implies a change of context and the preservation of information privacy when the pharmacy service accesses the prescribed medicines (information belonging to the hospital context) is mandatory. This raises new challenging questions such as the way that patients should protect their information, what information could be exchanged between different contexts, and who should manage the inter-contextual information.

Table 1 Comparative of different privacy-preserving systems

	[7]	[8]	[9]	[10]	[11]	[12]	[14]	[13]
Health privacy-oriented	✓	✓	✓				✓	
Context-awareness				✓	✓	✓		✓
Intra-context privacy	✓	✓	✓	✓	✓	✓	✓	✓
Preserve users' location				✓	✓	✓		✓
Preserve users' identity		✓	✓		✓	✓	✓	✓
Preserve users' context	✓	✓	✓		✓	✓	✓	✓
Policies defined by users	✓	✓			✓	✓	✓	✓
Policies set by the system						✓		✓
Multicontext solutions							✓	✓
Inter-context privacy							✓	✓

1.2 Contribution

In addressing the above issues and covering the aspects depicted in Table 1, the main contribution of this paper is a system called h-MAS (health-related Multicontext-Aware System). h-MAS is a solution oriented toward health contexts that enables the secure exchange of information, so allowing users not to have to manage the protection of their sensitive information. Specifically, h-MAS is an important evolution of MASTERY (Multicontext-Aware System That prEserves the useRs' privacY) proposed by [13], but oriented toward the management of the users' privacy in health scenarios by using policies that are intra- and inter-context. These policies protect the users' information by incorporating their consent to reveal their personal information. To this end, h-MAS suggests several sets of privacy-preserving and context-aware policies, called *profiles*, to users. These profiles are created by the administrator of each context. Administrators are trusted entities that know what kind of information is shaped within their contexts and, thus, what part of that information should be protected. Once users receive the profiles, they choose the most suitable profile according to their interests. After that, and in case the users want to control their information, they will be able to update the selected profile by adding, deleting, or modifying some of the policies that shape it. To that end, we have designed a mobile application that allows users to manage the privacy of their information in a friendly fashion. Intra- and inter-context policies form the privacy profiles that allow users to protect their location, personal information, activities they are doing at any given time, and information oriented to the context in which they are located. Finally,

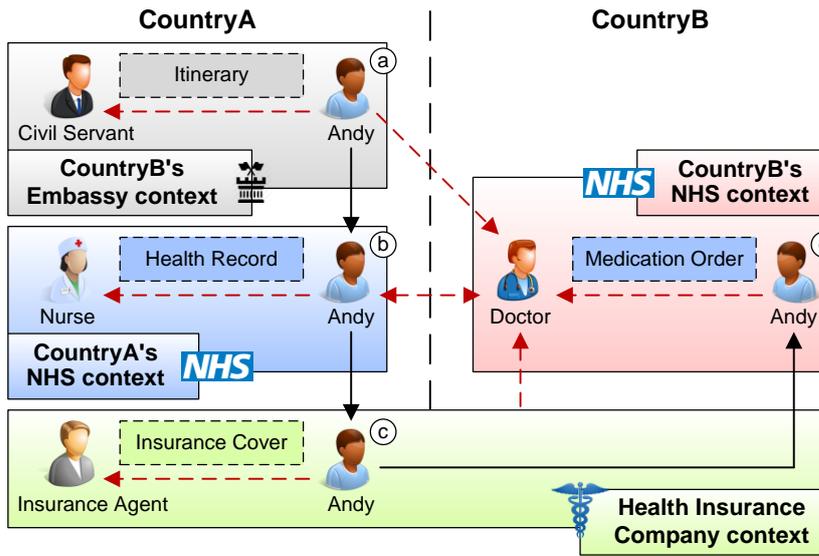


Fig. 1 Scenario with privacy concerns on the information of a given user

the complete definition of the information managed by h-MAS and the designed architecture to manage this information are provided in [15].

2 Scenario

The inter-context scenario below illustrates the privacy-related concerns that a user, named Andy, can find with respect to his private information. In Fig. 1, we show this scenario graphically, which is composed of four independent contexts distributed in two countries: *CountryA* with a clinic belonging to the National Health Service (NHS) and an Embassy of CountryB, and *CountryB* with a hospital belonging to the NHS of CountryB. Both contexts share an international Health Insurance Company. The exchange of information between the actors is shown with a (dashed) red line, and Andy's movements with a (solid) black line.

Andy is a citizen of CountryA who plans to visit CountryB. Before leaving CountryA, Andy has to request the visa to the Embassy of CountryB (which is located in CountryA), providing some information such as the days he will stay in CountryB, the places that he wants to visit, the purpose of the trip, etc. Once the visa is granted by CountryB, the information of the Andy's trip (date, itinerary, purpose, etc.) is stored by CountryB's Embassy.

After obtaining the visa, Andy goes to a clinic of CountryA's NHS context to get the required vaccines for CountryB. The Nurse, before vaccinating Andy needs to see his Health Record (HR) in order to know if he has allergies or some kind of illness. To this end, the Nurse accesses Andy's HR. Here is the first privacy concern, because the HR contains personal information like the Andy's Social History and he does not want the Nurse to know it. Finally, since Andy wants to have a health insurance valid in CountryB, he goes to an international Health Insurance company to purchase valid insurance for CountryB.

Some weeks later, when Andy is already visiting CountryB he has a heavy fever and decides to go to a hospital of CountryB's NHS context for a medical check-up. It is important to note that CountryA's NHS and the CountryB's NHS contexts share the structure to model the information, but the content is different. Once Andy is in the hospital, the Doctor needs to know if he has a Health Insurance valid for CountryB. The Doctor accesses the information about the Andy's Health Insurance and checks its cover. Here we have the second privacy concern because the Doctor can see private information about Andy, like Andy's bank account.

Once Andy is in the consulting room, the Doctor wants to know the places Andy has visited during the previous days. The Doctor accesses Andy's Itinerary information, which belongs to CountryB's Embassy. Here we have the third privacy concern because the Doctor must not access information that belongs to another context. Furthermore, when he accesses the Itinerary he can see private information such as the cities to be visited by Andy in the next days.

One week ago, Andy stayed in a city with a high risk of getting an infection. Therefore, the Doctor wants to know Andy's HR, which contains his immunization and Medication Orders. Here is the fourth privacy concern, as the Doctor accesses information that contains private data about Andy and his doctors.

When the medical check-up finishes, the Doctor generates a new Medication Order for Andy with the prescribed medicine. Once Andy comes back to CountryA, if he visits a hospital or clinic of CountryA's NHS context and the staff accesses the medication order given in CountryB's NHS context, there will be at fifth privacy concern.

In order to address the concerns introduced during this Section, it is necessary to provide some management mechanisms with which to protect the users' information.

3 Preserving users' privacy

Privacy policies should allow users to manage when, where, how, and to whom their private information can be revealed. h-MAS provides users with a group of context-aware and privacy-preserving policies called *profiles*. These profiles are specific to the context in which users are located, aimed to protect the privacy of their personal information. Furthermore, the profile selected by the user can be modified by adding, modifying, or deleting its policies according to his/her interests. The policies that are part of the profiles managed by h-MAS are composed of the following elements:

$$Type \wedge Maker \wedge Target \wedge Requester \wedge [What, Where, When, How] \rightarrow Result$$

h-MAS classify the policies into two groups: intra- and inter-context. The *intra-context policies* are in charge of protecting the information in a given context, while the *inter-context policies* protect the information between different contexts. As an example of these policies, considering again the scenario of Section 2. Both groups of policies are, in turn, composed of two different policies. First, the *disclosure policies* are in charge of indicating what information of the users can be shared. Second, the *reveal policies* with which the users can decide where, when, and how their information can be shared.

3.1 The intra-context policies

The *intra-disclosure policies* indicate *what* information the *target* wants to share with a given *requester*. The only restriction of the intra-disclosure policies is that the *maker*, *requester*, and *what* fields must belong to the same context. It is important to note that intra-disclosure policies do not indicate where, when, or how the information is revealed. Following the scenario of Section 2, we need an intra-disclosure policy to solve the first privacy concern. The NHS Administrator of CountryA needs to indicate that patients (role in an NHS context) could disclose their EHR to any Nurse, where the latter is another role in CountryA's NHS context. Disclosing the EHR allows the Nurse to know Andy's allergies or medication orders without revealing Andy's social history. An example of this intra-disclosure policy is given by:

Id: **ClinicIntraD** \wedge *Type:* **IntraDisclosure** \wedge
Maker: **CountryANHSAAdmin** \wedge *Target:* **Patient** \wedge *Requester:* **Nurse** \wedge
What: **EHR** \rightarrow *Result:* **Disclosure**

On the other hand, the *intra-reveal policies* indicate *where*, *when*, and *how* the target's information can be shared. This kind of intra-reveal policy is related to the previous intra-disclosure one through the target and requester elements. In this sense, this policy activates the disclosure policies when the users are in certain places or contexts. Following the scenario of Section 2, in order to activate the policy previously defined (ClinicIntraD) an intra-reveal policy is necessary. Specifically, the Administrator of CountryA's NHS context allows the Nurse to access the information defined by the intra-disclosure policy ClinicIntraD, defined earlier when the Patient is in the Consulting Room of the clinic. This policy is defined below.

Id: **ClinicIntraR** \wedge *Type:* **IntraReveal** \wedge
Maker: **CountryANHSAAdmin** \wedge *Target:* **Patient** \wedge *Requester:* **Nurse** \wedge
Where: **ConsultingRoom** \rightarrow *Result:* **Reveal**

3.2 The inter-context policies

The *inter-disclosure policies* are aimed at preserving the exchange of information between different contexts. When a user of a given context wants to access information belonging to another context, it is necessary for the information's context owner to leave it accessible to be exchanged. In these policies, the *maker* must belong to the context of the information and the *what* field must contain information about the maker's context. In the scenario of Section 2, we detected an information exchange between different contexts: the Doctor accessing the Insurance Cover, Itinerary, and EHR of Andy. Therefore, in order to solve the second concern on privacy the next policy indicates that Andy discloses the Cover of his Health Insurance to the staff of the hospital belonging to CountryB's NHS context. In this policy, the Insurance Agent is in charge of deciding who can access this information with an inter-disclosure policy.

Id: **InsuranceInterD** \wedge *Type:* **InterDisclosure**[Hospital] \wedge
Maker: **InsuranceAgent** \wedge *Target:* **Andy** \wedge *Requester:* **HospitalStaff** \wedge
What: **InsuranceCover** \rightarrow *Result:* **Disclosure**

Regarding the third privacy concern, the Civil Servant defines the inter-disclosure policy shown below indicating that Andy discloses his Itinerary to the staff of the hospital belonging to CountryB's NHS context.

Id: **EmbassyInterD** \wedge *Type:* **InterDisclosure**[Hospital] \wedge
Maker: **CivilServant** \wedge *Target:* **Andy** \wedge *Requester:* **HospitalStaff** \wedge
What: **Itinerary** \rightarrow *Result:* **Disclosure**

In order to solve the fourth privacy concern of Section 2, the Nurse defines the inter-disclosure policy shown below. In this policy, the Nurse discloses Andy's EHR. Since Andy did not reveal his PHR (Personal Health Record) to the staff of the clinic belonging to CountryA's NHS context, the Nurse cannot disclose this information to another context.

Id: **ClinicInterD** \wedge *Type:* **InterDisclosure**[Hospital] \wedge
Maker: **Nurse** \wedge *Target:* **Andy** \wedge *Requester:* **HospitalStaff** \wedge
What: **EHR** \rightarrow *Result:* **Disclosure**

Finally, the fifth privacy concern of Section 2 is solved by the next policy, which discloses Andy's Medication Order given by the Doctor of the Hospital context to the NHS Staff of CountryA.

Id: **HospitalInterD** \wedge *Type:* **InterDisclosure**[CountryANHS] \wedge
Maker: **Doctor** \wedge *Target:* **Andy** \wedge *Requester:* **NHSStaff** \wedge
What: **MedicationOrder** \rightarrow *Result:* **Disclosure**

On the other hand, the inter-reveal policies are similar to the intra-reveal policies, although the former are totally oriented to operate between contexts. These inter-reveal policies indicate *where*, *when*, and *how* the information (previously established by the inter-disclosure policies) is revealed.

In the scenario of Section 2, in order to allow the Doctor to access the Cover of Andy's Health Insurance the Administrator of CountryB's NHS context needs to define an inter-reveal policy. This policy will reveal the Cover of the Foreign Patient (Andy) to the Doctor.

Id: **1HospitalInterR** \wedge *Type:* **InterReveal**[HealthInsuranceCompany] \wedge
Maker: **CountryBNHSAdmin** \wedge *Target:* **ForeignPatient** \wedge *Requester:* **Doctor** \wedge
Where: **ConsultingRoom** \rightarrow *Result:* **Reveal**

Following the scenario of Section 2, in order to allow the Doctor to access Andy's itinerary we need the inter-reveal policy that reveals the information allowed by the policy EmbassyInterD. This policy defines that when a Foreign Patient (like Andy) is in the hospital of CountryB's NHS, his/her Itinerary is revealed to the Doctor. Although this policy only defines information about CountryB's NHS context, the information to be revealed belongs to the CountryB's Embassy context.

Id: **2HospitalInterR** \wedge *Type:* **InterReveal**[CountryBEmbassy] \wedge
Maker: **CountryBNHSAdmin** \wedge *Target:* **ForeignPatient** \wedge *Requester:* **Doctor** \wedge
Where: **Hospital** \rightarrow *Result:* **Reveal**

To reveal the information allowed by the policy ClinicInterD, CountryB's NHS Administrator needs to define a new inter-reveal policy in which he/she allows access to the EHR of the Foreign Patient when he/she is in the Consulting Room. This policy just reveals the information allowed by the context to which the information (policy identifier ClinicInterD defined in the CountryA's NHS context) belongs.

Id: **3HospitalInterR** \wedge *Type:* **InterReveal**[CountryANHS] \wedge
Maker: **CountryBNHSAdmin** \wedge *Target:* **ForeignPatient** \wedge *Requester:* **Doctor** \wedge
Where: **ConsultingRoom** \rightarrow *Result:* **Reveal**

Finally, if Andy comes back to CountryA and the NHS accesses the information of Andy's Medical Order, the CountryA's NHS context has to define a new inter-reveal policy.

4 Management of the users' information privacy by h-MAS

This section shows how h-MAS protects the privacy of the users' information using the scenario of Section 5. Fig. 2 depicts when Andy is in CountryB's Embassy to get the visa to travel to that country. Andy uses his smartphone with the h-MAS application shown in Section 2 to protect his information. In this sense, h-MAS detects him in accordance with the information provided by the embassy's location infrastructure. Then, h-MAS offers him several context-aware profiles, such as Visitor or Citizen (step 3 in Fig. 2). These profiles are suggested by CountryB's Embassy Administrator to h-MAS (steps 1 and 2), and h-MAS is in charge of suggesting them to Andy. Once Andy receives the list of available in his mobile device, he chooses the most appropriate for him, the Visitor profile (step 4), and h-MAS stores and activates the profile to the CountryB's Embassy context (step 5). When Andy is before the Civil Servant, the latter asks Andy for the trip information (purpose, itinerary, date, etc.) and h-MAS stores this information (steps from 6 to 9). Finally, the Civil Servant defines the policy EmbassyInterD (presented in Section 3.2) to provide the Itinerary information to the Hospital context.

Fig. 3 shows the sequence diagram when Andy is in the clinic to get the vaccines, and the Nurse wants to access Andy's EHR. h-MAS detects Andy and offers several context-aware profiles, Andy chooses one of them, and h-MAS stores and activates the profile in the context in which Andy is located (steps from 1 to 5). Once Andy is in the consulting room, the Nurse wants to access Andy's EHR to know if he has allergies or illnesses (step 6). The Nurse then uses the NHS application that manages the information available in that context. This application asks h-MAS for Andy's information, and h-MAS checks if Andy's profile allows the Nurse to do it (step 7). To this end, h-MAS has a component, called *Engine*, which is in charge of managing the context-aware information and Andy's personal

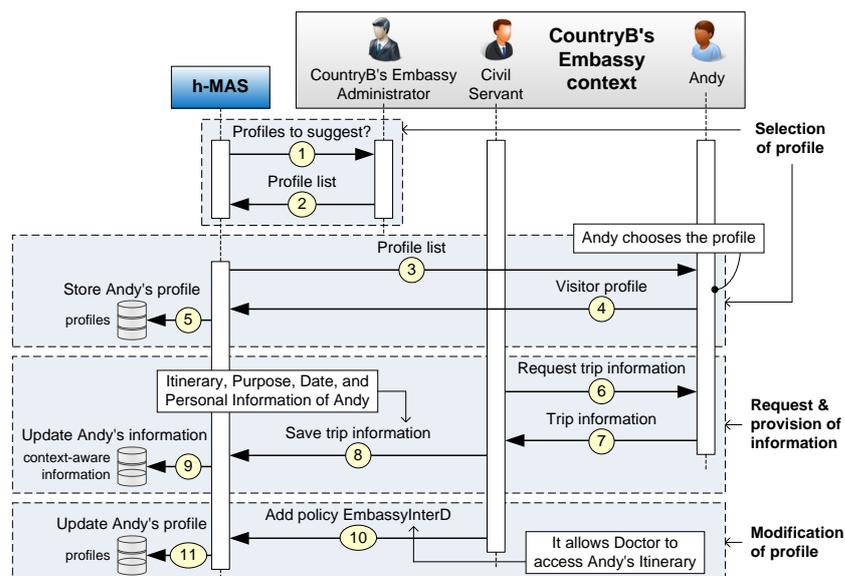


Fig. 2 Sequence diagram of h-MAS in CountryB's Embassy context

information and profiles. Specifically, the engine uses the previous information to decide if the Nurse has permission to access the requested information. Since the ClinicIntraD and ClinicIntraR policies of Andy's profile allow the Nurse to access the EHR of Andy, h-MAS asks Andy for confirmation to release his information (step 8); otherwise, the confirmation would not be requested. At this point, Andy receives a request in his mobile device, Andy accepts the request and his information is released to the Nurse (steps 9 and 10).

Once Andy is vaccinated, the Nurse wants to modify the EHR of Andy in order to update the information. The Nurse uses again the NHS application to ask h-MAS for access to Andy's EHR (step 11). The h-MAS's Engine manages the required information, infers that the action is allowed (step 12), and asks Andy for confirmation (step 13). Once Andy accepts (step 14), the Nurse updates Andy's EHR with the vaccines (steps 16 and 17). Finally, since Andy is going to visit CountryB, the Nurse updates the Traveler Patient profile of Andy (steps 18 and 19) with the policy ClinicInterD presented in Section 3.2. This policy allows the hospital of CountryB's NHS context to access Andy's EHR. It is important to note that before updating the Andy's Traveler Patient profile, the nurse requested him the authorization to make it. This process has not been included in Fig. 3 because it is similar to the previous confirmation processes and it would increase the diagram's complexity.

Before leaving CountryA, Andy changes context again when he goes to the international Health Insurance Company, in order to take out Health Insurance valid in CountryB. When he is at the insurance company, h-MAS provides him with several profiles and he selects the most appropriate. Once Andy decides his insurance, he pays for it and the Insurance Agent stores the information using h-MAS. Finally, the Insurance Agent defines and stores in h-MAS the InsuranceInterD policy (explained in Section 3.2). This policy provides the information

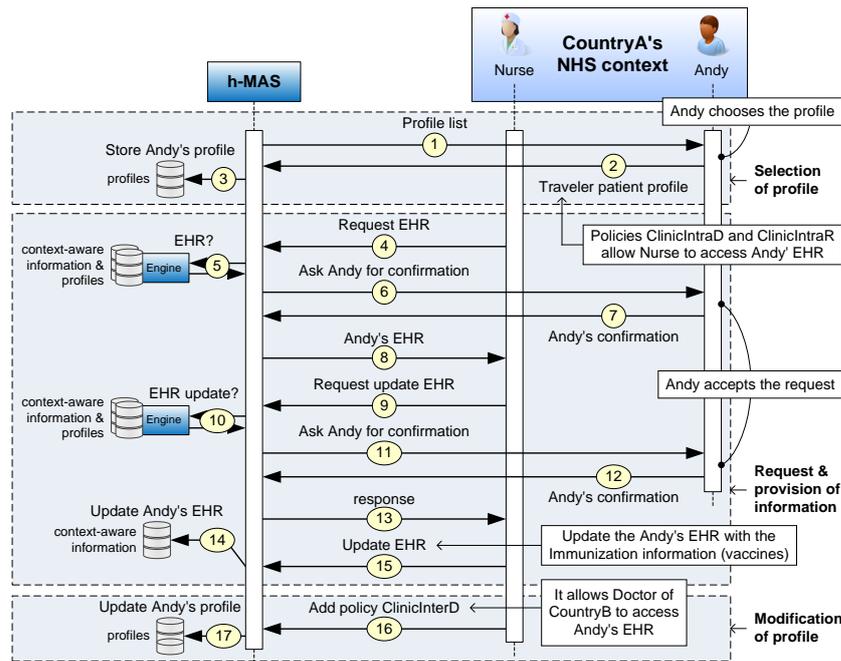


Fig. 3 Sequence diagram of h-MAS in CountryA's NHS context

about the cover of Andy's Health Insurance to the CountryB's NHS context. The steps of the process explained in this paragraph are similar to the ones of Fig. 3, but changing the context, actors, information, and policies. When Andy is in the CountryB's NHS context, the sequence diagram of h-MAS is similar to the previous ones.

Finally, it is worth noting that to ensure the h-MAS's usability, the users just interact with the system to choose the preferred profiles and to consent to the release of their information. In that sense, next Section shows how users make it.

5 How users manage their profiles

Although an initial set of profiles is defined by administrators, h-MAS allows users to manage the privacy of their information, modifying the suggested profiles through a *Privacy application* with which users can create, delete, and modify their profiles and policies. Thus, the usability of the approach proposed can be achieved.

Fig. 4 shows how users can select a given privacy-preserving profile to protect his/her sensitive information, edit an already defined profile, or create a determined policy by using the *Privacy application* of the h-MAS architecture. Specifically, Fig. 4a shows how Andy's context is discovered and how he can choose the most suitable profile for him in that context. In this example Andy chooses the Traveler Patient profile that is available in the CountryA's NHS context. Furthermore, by using the *Privacy application*, Andy can edit the suggested profiles, create,

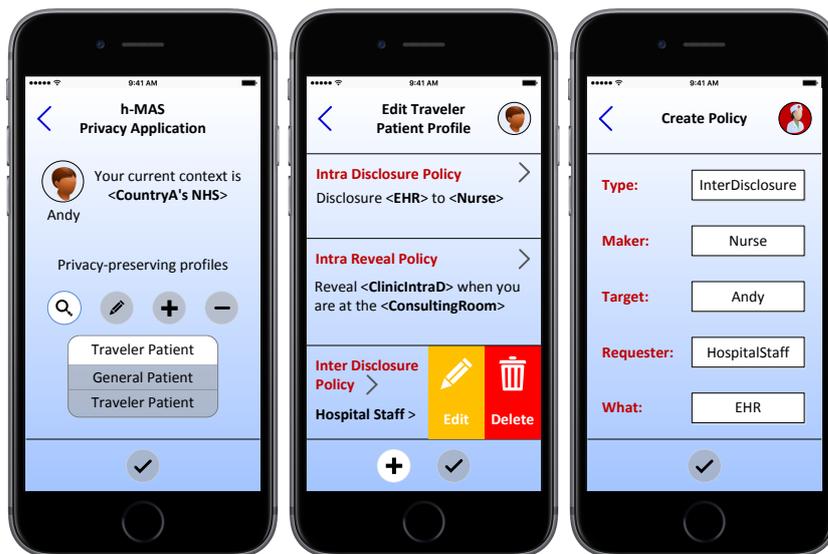


Fig. 4 How a user can choose a given profile and how its policies can be created or edited with a mobile application: a) Andy chooses Traveler Patient to protect his information in the NHS context; b) Andy edits the Traveler Patient profile to modify the third policy; c) Andy's Nurse generates an Inter Disclosure Policy to control the Andy's EHR.

or delete new profiles. Fig. 4b depicts how Andy can edit his *Traveler Patient* profile adding or deleting policies. Finally, Fig. 4c shows how users can create a new policy for a given profile. Specifically, this figure depicts how the Nurse of Andy modifies the Traveler Patient profile of Andy with the ClinicInterD policy presented in Section 3.2.

6 Results

The time needed to load and infer information (reasoning time) is one of the most important metric to know the throughput of systems based on semantic web [16]. In this sense, an experiment is presented in this section to measure how the computing *time of reasoning* is in inter-context scenarios.

As experimental setting, the tests were carried out in a dedicated PC with an Intel Core i7-3770 3.40 GHz, 16 GB of RAM, and an Ubuntu 14.04 LTS as operative system. The results shown below were obtained by executing the tests 100 times and computing their arithmetic mean. In our experiment, the information about users and contexts is shaped with ontologies defined in OWL 2 (Web Ontology Language) [17]. On the other hand, the policies that are part of the users' privacy profiles are expressed in SWRL (Semantic Web Rule Language) [18]. In order to decide what information is revealed, where, when, how and to whom, h-MAS uses the Pellet reasoner [19]. This reasoner receives the ontological models generated by the Jena API [20] and applies the SPARQL queries [21] to obtain the requested information.

In order to ascertain the reasoning time in inter-context scenarios and its scalability, we have conducted an experiment in the health scenario presented in Section 2, with different levels of complexity. The complexity depends on the number of individuals present in the ontologies and the number of semantic rules forming the policies. For this experiment and in order to create as realistic a scenario as possible, we have obtained the percentages of the individuals considered in the health environment from *The World Bank* [22]. In more detail, we have based the percentages on the official number of patients, doctors, and nurses per population in different countries of the world. For instance, Patient is 10 % of the individuals; Space 75 %; context-aware elements, such as HealthRecord, HealthInsurance, or Trip, 10 %; and others, such as NHSStaff or NHSService, 5 %. In order to conduct the experiment, we started with 30,000 individuals, which were increased by 30,000 in each step. Table 2 shows the relationships between the individuals and the statements generated by the reasoner, which indicates the complexity of our ontologies.

Table 2 Individuals and statements per population

Population	0	1	2	3	4
Individuals	30,000	60,000	90,000	120,000	150,000
Patients	3,000	6,000	9,000	12,000	15,000
Statements	247,140	494,280	741,420	988,560	1,235,700

We used the previous populations in order to check the *reasoning time* in inter-context scenarios, where the information is shaped in different ontologies and it is necessary to combine two ontologies. Fig. 5 depicts how the reasoning time (y-axis) in inter-context scenarios varies depending on the populations of two ontologies (x-axis).

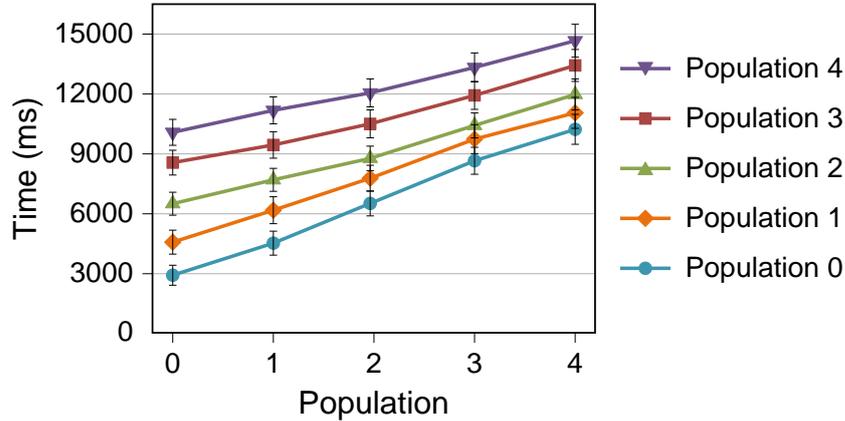


Fig. 5 Reasoning time combining ontologies from different contexts (inter-context) with different populations

The previous experiment demonstrated that when our solution combines ontologies in inter-context scenarios, the reasoning time is less than the sum of the reasoning time of the individual ontologies. This is because the ontologies share individuals and properties, so the number of statements is not the sum of the individual ontologies' statements. It is important to notice that although the reasoning time is measured in seconds, users do not have to wait for this time in order to receive the requested information. This time is just needed in the process of checking the consistency of the ontology, which must be performed when the h-MAS ontology is updated. It is important to consider that other important questions of systems based on semantic web technologies, like the query and intra-context reasoning times, have already been analyzed with positive results in [12].

7 Conclusions

We have proposed a privacy-preserving multicontext-aware solution called h-MAS that protects users' information in health scenarios. h-MAS is an evolution of MASTERY oriented toward health scenarios. It provides several privacy-preserving and context-aware profiles and suggests them to users of the proposed system. These profiles are formed by a pool of privacy policies so as to protect the users' location, personal information, the activities they are doing at any given time, and the information oriented toward the context in which they are located. The users of h-MAS can modify the profiles by adding, deleting, and modifying their policies to control what, where, when, how, and to whom they want to reveal their information.

As further steps in this research, we plan to migrate our architecture to a decentralized environment, by making use of federation mechanisms. We also plan to provide more intelligence to h-MAS in order to offer customized profiles that consider the actions performed by the users on previous visits to the context.

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References

1. Ngai EWT, Poon JKL, Suk FFC, Ng CC. "Design of an RFID-based healthcare management system using an information system design theory." (2009). *Information Systems Frontiers*. 11(4), 405–417.
2. Huang LC, Chu HC, Lien CY, Hsiao CH, KT. "Privacy preservation and information security protection for patients' portable electronic health records." (2009). *Computers in Biology and Medicine*. 39(9), 743–750.

3. Schilit B, Adams N, Want R. "Context-aware computing applications." (1994). in Proceedings of the 1st Workshop on Mobile Computing Systems and Applications. 85–90.
4. Abowd GD, Dey AK, Brown PJ, Davies N, Smith M, Steggle P. "Towards a better understanding of context and context-awareness." (1999). in Proceedings of the 1st International Symposium on Handheld and Ubiquitous Computing. 304–307.
5. Abbas A, Khan SU. "A review on the state-of-the-art privacy-preserving approaches in the e-Health clouds." (2014). *IEEE Journal of Biomedical and Health Informatics*. 18(4), 1431–1441.
6. Gupta B, Agrawal DP, Yamaguchi S. "Handbook of Research on Modern Cryptographic Solutions for Computer and Cyber Security," (2016). IGI Global Publisher, USA.
7. Wu R, Ahn GJ, Hu H. "Secure sharing of electronic health records in clouds." (2012). in Proceedings of the 8th International Conference on Collaborative Computing: Networking, Applications and Worksharing. 711–718.
8. Haas S, Wohlgemuth S, Echizen I, Sonehara N, Müller G. "Aspects of privacy for electronic health records." (2011). *International Journal of Medical Informatics*. 80(2), 26–31.
9. Van Gorp P, Comuzzi M. "Lifelong personal health data and application software via virtual machines in the cloud." (2014). *IEEE Journal of Biomedical and Health Informatics*. 18(1), 36–45.
10. Myles G, Friday A, Davies N. "Preserving privacy in environments with location-based applications." (2003). *IEEE Pervasive Computing*. 2(1), 56–64.
11. Jagtap P, Joshi A, Finin T, Zavala L. "Preserving privacy in context-aware systems." (2011). in Proceedings of the 5th IEEE International Conference on Semantic Computing. 149–153.
12. Huertas Celdrán A, García Clemente FJ, Gil Pérez M, Martínez Pérez G. "What private information are you disclosing? A privacy-preserving system supervised by yourself." (2014). in Proceedings of the 6th International Symposium on Cyberspace Safety and Security. 1221–1228.
13. Huertas Celdrán A, García Clemente FJ, Gil Pérez M, Martínez Pérez G. "MASTERY: A multicontext-aware system that preserves the users' privacy." (2016). in Proceedings of the 2016 IEEE/IFIP Network Operations and Management Symposium. 523–528.
14. Martino LD, Ni Q, Lin D, Bertino E. "Multi-domain and privacy-aware role based access control in eHealth." (2008). in Proceedings of the 2nd International Conference on Pervasive Computing Technologies for Healthcare. 131–134.
15. University of Murcia. "h-MAS architecture and ontologies." [http://dharma.inf.um.es/h-mas\(2016\)](http://dharma.inf.um.es/h-mas(2016)). Accessed 12 Jan 2017.
16. Dentler K, Cornet R, Ten Teije A, De Keizer N. "Comparison of reasoners for large ontologies in the OWL 2 EL profile." (2011). *Semantic Web*. 2(2), 71–87.
17. W3C Recommendation. "OWL 2 web ontology language: Structural specification and functional-style syntax (2nd ed.);" 2012.
18. W3C Member Submission. "SWRL: A semantic web rule language combining OWL and RuleML." 2004.
19. Sirin E, Parsia B, Cuenca Grau B, Kalyanpur A, Katz Y. "Pellet: A practical OWL-DL reasoner." (2007). *Web Semantics: Science, Services and Agents on the World Wide Web*. 5(2), 51–53.
20. The Apache Software Foundation. "The Apache Jena2 ontology API." [http://jena.apache.org/documentation/ontology\(2016\)](http://jena.apache.org/documentation/ontology(2016)). Accessed 12 Jan 2017.
21. W3C Recommendation. "SPARQL query language for RDF." 2008.
22. The World Bank. "Percentages of medical information around the world." [http://data.worldbank.org\(2016\)](http://data.worldbank.org(2016)). Accessed 12 Jan 2017.