Employing Opportunistic Networks in Dementia Patient Monitoring

Radu-Ioan Ciobanu
University POLITEHNICA of Bucharest, Bucharest, Romania
radu.ciobanu@cti.pub.ro

Ciprian Dobre
University POLITEHNICA of Bucharest, Bucharest, Romania
ciprian.dobre@cs.pub.ro

ABSTRACT

By 2050, 135.5 million people will suffer from dementia worldwide. Ambient Assisted Living (AAL) technologies can help dementia patients enjoy an independent life. In particular, communication is vital to any AAL system. Opportunistic networking uses low-cost wearable devices to exchange packets at a close range, in cases where there is limited or no infrastructure. In this chapter, we propose and describe an autonomous patient monitoring support system based on opportunistic communication. The monitored patient wears non-intrusive sensors, computing devices and actuators, forming a body area network (BAN). The BAN can provide memory impairment support services for the patient, and is used to construct personalized condition-monitoring patient models to evaluate against a set of potential life-threatening events. We present two data transfer algorithms, and show that they are able to offer good hit rates, while decreasing congestion and overhead when compared to other existing solutions.

Keywords - dementia; patient monitoring; mobile technologies; opportunistic; body area network

1. INTRODUCTION

In recent years, mobile devices have become ever-present all around us. Ranging from simple sensors, smartphones and tablets, to high-range mobile access points, mobile devices can be found everywhere. A way of organizing these heterogeneous devices into a coherent unit that serves well-defined purposes is by creating an opportunistic network (ON) where they act as nodes. ONs are generally composed exclusively of mobile devices that wish to communicate between each other, although there may be no direct route between them at any time. Nodes in opportunistic networks are not aware of the topology of the network and of the other participating nodes. The only information they have is learned from encounters with other devices, through short-range proximity communication. Opportunistic networks are based on a paradigm entitled store-carry-and-forward. It implies that a node wishing to send a message to another node starts by storing the data and carrying it around the network, until it finds a suitable destination for it. Such a destination is not necessarily the message’s destination, but it can also be another node that has a better chance of delivering the message to the destination than the current carrier. Thus, through collaboration and altruism, ON nodes end up delivering data even when there is no direct connectivity between two nodes.

There are many real-life use cases where opportunistic networks can or have already been employed successfully, because not only can they help ease communication in situations where two nodes may never be connected, but they can also decrease the costs of communication. This can be done, for example, by using short-range data exchanges (such as Bluetooth or WiFi Direct) instead of cellular communication (such as 3G or LTE). One of the first ever real-life applications for ONs was wildlife tracking, i.e., recording the movement and behavior of animals in their natural habitat without being intrusive. Special tags containing GPS sensors and close-range communication capabilities are attached to the animals, and fixed or mobile access points are set up in key places in the animals' habitats. Whenever two tagged animals encounter each other, information is exchanged between the devices. When a tagged animal comes in range of an access point, it uploads all available information, which may include data gathered not only from the carrier, but also from other encountered animals. Another situation where opportunistic networks have been successfully employed is in offering Internet access in limited conditions, where no infrastructure exists, such as rural areas where the deployment of Internet is not feasible or cost-effective (e.g., Indian villages). Kiosks are built in the village centers, equipped with digital storage and wireless communication devices, which interact periodically with mobile base stations mounted on buses, motorcycles or bicycles. These mobile stations collect the data from the kiosks and deliver it to Internet access points located in the larger cities, and vice versa.

Opportunistic networks are also appropriate for disaster management, when a natural disaster such as an earthquake, a tsunami or an explosion might disrupt the physical components of the network, such as switches and cables. In these situations, the cellular infrastructure cannot be used, so there is a need for ensuring more efficient and dependable solutions for the rescue missions, by using the unaffected components of the static infrastructures as nodes in an ON, along with mobile devices (such as smartphones) belonging to nearby citizens or survivors of the disaster, with the purpose of offering connectivity where otherwise there would be none, or simply decreasing congestion. Congestion problems may also appear in very crowded areas such as concerts, sporting events, amusement parks, where cellular communication is spread very thin by the large number of open connections from the same geographical location. Opportunistic networks can thus be employed to reduce the cellular communication to fewer nodes and access points, which are then able to spread the data to the other network participants.

Another situation where opportunistic networks could prove useful is in smart cities, which monitor and integrate the conditions of all their critical infrastructures (such as roads, rails, airports, power, water, etc.) in order to optimize resource usage and to plan preventive maintenance activities. By using opportunistic networks, every sensor in a smart city can be leveraged in order to have a big picture of the entire town, without the need of long-range communication capabilities. Sensors simply communicate with any device in range, which can then transport the data to access points that can communicate faster and with a longer range. Other opportunities for ONs exist, such as advertising, geographical area-based floating content, context-aware platforms or distributed social networks.

Although there are multiple advantages in using opportunistic networks, as seen above, there are several challenges that have to be taken into consideration when deploying ONs in real-life situations. The first of these challenges is the very premise of ONs itself, namely that the lack of connectivity at all times leads to a potential lack of end-to-end paths. Thus, if the network is very sparse (i.e., there are few nodes spread on a large area), contact opportunities are very low and so not all nodes may receive the messages destined for them. Moreover, in sparse networks, large delays in message delivery may be incurred. Closely related to this challenge is the decision of selecting a message's next hop. Ideally, content should be spread epidemically in the network, so whenever two nodes meet, they should exchange all data between each other. However, this may lead to congestion issues in the network, as well as on a node level, since the devices have relatively low storage capabilities. Moreover, if the nodes travel at high speeds, the duration of a contact might not be sufficient for exchanging all the content between the encountering nodes. Thus, informed decisions should be made in order to decide if an encountered node is a suitable carrier for a given message. Various routing and dissemination algorithms have been proposed over the years, which take advantage of a node's encounter history, its social relationships with other nodes, or its interests, in deciding whether an encountered device is a suitable forwarder. Furthermore, the nodes from an opportunistic network are mobile devices that generally have limited battery capacity, so this information should also be taken into consideration when performing routing decisions, in order to optimize a node's lifetime.

We believe that opportunistic networks can be successfully applied to the area of dementia patient monitoring. We envision an infrastructure where the patients are being monitored by various sensors, each of them offering different types of readings. These sensors would have short-range communication capabilities, so they can exchange information with data-collecting devices that are carried around the wards by the nurses or the doctors which visit the patients on a regular basis. When two doctors meet, their devices can also exchange the collected data, which is uploaded to the main processing and storage units whenever the doctors are in their proximity. If the patients are mobile (e.g., they have a daily routine which requires them to move to different rooms or wards), they could also be equipped with data-collecting devices. These devices would not only collect data from their sensors, but they would also be able to perform individual computations based on the sensors' readings, in order to potentially alert the doctors if critical situations arise. For such critical situations, the hospital's cellular or WiFi infrastructure can be used, but our proposed solution would drastically reduce the costs of maintaining such an infrastructure. Moreover, opportunistic networks can also be used to disseminate information among the hospital staff, based on their interests, area of expertise, patient list, etc. Opportunistic networks can also be used to track patients suffering from dementia, in order to autonomously detect and alert competent authorities when the patients deviate from their usual walking routes and might get potentially lost. Thus, they are perfect candidates to construct middleware support for services designed to offer a decent quality of life, and perceived health and well-being, for dementia patients.

2. PROBLEM STATEMENT

Human memory is notoriously faulty. We constantly forget important dates, meetings, names, and, let's not forget, the proverbial car keys. It is probably safe to predict that this is only going to get worse: the world is becoming more complex and information-driven, while the human memory is not improving, but in fact is probably becoming worse, due to this information overload. Thus, it is no wonder that human memory has been the subject of various studies in biology, cognitive science, and in psychology. Today, we have studies that relate stress to the difficulty of transferring information from short-term memory to medium-term memory. This difficulty is often the root of a reduction in personal every day's efficiency as things to do tend to come to mind unordered and unplanned. When it comes to medical problems, dementia is the term used to describe various symptoms of cognitive decline such as forgetfulness[1].

For memory-related medical problems such as dementia, Information and Communication Technology (ICT) has an important role in patient monitoring and even for treatment support. More and more people see ICTs as part of their everyday lives, and this includes people with dementia. For example, offering activities that use technology can encourage people to engage better with medical services. ICTs open up avenues for intellectual stimulation for everyone, regardless of their interests and capabilities. The Internet puts a world of knowledge at one's fingertips. Encouraging staff to use ICTs with people with dementia means they will improve their own ICT knowledge and skills. It also means the working day can be made more varied, which improves morale for staff and people with dementia alike.

While the likelihood of having dementia increases with age, it is not a normal part of aging. Before we had today's understanding of specific disorders, "going senile" used to be a common phrase for dementia (sometimes also referred by the term "senility"), which was misunderstood as a standard part of getting old (Ninds, 2013; ALZ, 2013). Dementia describes a number of brain disorders that are severe enough to affect daily activities. Alzheimer's disease is probably among the most known and most common[2].

According to an analysis of the most recent census, 4.7 million people aged 65 years or older, in US alone, were living with Alzheimer's disease in 2010 (Hebert et al, 2013). The Alzheimer's Association estimates in its 2013 report (ALZ, 2013) that over a tenth of people aged 65 years or more have Alzheimer's disease, and this proportion rises to about a third of people aged 85 and older. The organization indicates that Alzheimer accounts for between 60% and 80% of all cases of dementia, with vascular dementia caused by stroke being the second most common type.

3. APPLICATIONS FOR MOBILE NETWORKS IN DEMENTIA PATIENT MONITORING

Technologies related to multi-hop (mobile) ad-hoc networking emerged in the 1990s, when off-the-shelf wireless devices became able to provide direct network connections among mobile devices: Bluetooth (IEEE 802.15.1) for personal area networks, and the 802.11 standards family for high-speed wireless LAN. Wireless Sensor Networks (WSNs), in particular, are a special class of multi-hop ad-hoc networks developed to control and monitor a wide range of events and phenomena. In WSNs, a number of sensor nodes are typically deployed (in a dense and possibly random manner) inside a monitoring area. The information collected by the sensor nodes is delivered, by following the multi-hop paradigm, to a sink node and through this to nodes connected to the Internet.

WSNs were long seen as perfect candidates for health monitoring systems (i.e., wireless mobile sensors can be worn by the patient). With an increasing cost of healthcare and a growing population of seniors in nursing homes and hospitals worldwide, patient monitoring

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[1] We acknowledge that dementia is not a clinical diagnosis itself, unless an underlying disease or disorder has been identified.

[2] Light cognitive impairments, by contrast, such as poorer short-term memory, can happen as a normal part of aging (we slowly start to lose brain cells after around the age of 20). This is known as age-related cognitive decline, not dementia, because it does not cause the person or the people around them any problems (NINDS, 2013).

using wireless technologies is considered as a solution to both improving the quality of healthcare and reducing the rate of increase for healthcare services (Akyildiz et al, 2002; Gieras, 2003). Physiological sensors (e.g., to measure EKG, blood pressure, and temperature) can be used to automatically collect physiological parameters to be delivered via a body-area network to devices that can be worn and for real-time processing and/or storing for future use (long-term observation) (Varshney, 2008). For example, the CodeBlue system developed at Harvard University exploits a WSN to raise an alert when vital signs fall outside of the normal parameters (Malan et al, 2004). The system monitors heart rate, oxygen saturation, and EKG data and relays the data over a short-range wireless network to a set of devices, including ambulance-based terminals. However, as developers and practitioners alike remarked, WSNs are not necessarily ideal technological support for patient monitoring, as they face a difficult challenge: they represent an engineering approach designed to hide node mobility by constructing "stable" end-to-end paths as in the Internet. When the patient is moving around, as in real-world hospital environments, coping seamlessly with mobility is not so easy to handle in traditional WSNs - possibly, due to interferences or lack of wireless coverage, there is simply no support to form a path between the sensor (patient) to its data sink (doctor) in one single session.

In general, patient monitoring involves periodically transmitting routine vital signs of patients across certain boundaries (and, in some cases, alerting signals when vital signs cross a threshold; in other cases, the data processing of vital signs is moved on a specialized in-the-Cloud platform). As one might think, there are many challenges in wireless monitoring of patients, including the coverage, reliability and quality of monitoring (Varshney, 2008). The current work done in patient monitoring includes, among others, home monitoring (Lee et al, 2000), wireless systems for digitized EKGs (Khoor et al, 2001), hospital-wide mobile monitoring systems (Pollard et al, 2001), mobile telemedicine (Hung & Zhang, 2003; Pattichis et al, 2002), or real-time home monitoring of patients (Mendoza & Tran, 2002).

A variety of approaches previously made attempts to address the issues of reliable and efficient message delivery from deployed sensors to central processing units (for an analysis we refer the reader to Braem et al, 2008). The problem is finding a trade-off between reliability and energy efficiency, because any patient monitoring system will need to maximize the amount of delivered messages, with minimum energy consumption. In an ad-hoc environment, the success of message delivery is not only related to the consumed power, but also depends on the cooperation of neighboring devices. As specified in (Varshney, 2007), it is impossible to use a single method to coordinate multiple entities in a dynamic and complex environment. Apparently, patient monitoring has become an interdisciplinary topic and needs more intelligent technologies than other subjects (e.g., artificial intelligence). The Ambient Cardiac Expert (ACE) monitoring system (Sehgal et al, 2007) is a cardiac patient monitoring system which collects physiological data observed by sensor networks (together with gene expression data) to predict the heart failure rate. Clinical data monitored by attached sensors on patients' bodies is used to generate training data to predict the odds of heart failure.

Elderly dementia patient monitoring is on the other side of mobile healthcare systems. Unlike cardiac-assistance, in dementia patient monitoring delays can in some cases be tolerated (i.e., when monitoring the location of the patient, and in cases where the social interaction with the patient surroundings is actually encouraged). For example, (Lin et al, 2008) presents an indoor and outdoor active safety monitoring mechanism, built based on radio frequency identification (RFID) technology. The monitoring system can automatically remind caregivers once an elderly patient is close to a dangerous area or too far from caregivers. During the information exchange process, the Tame Transformation Signatures (TTS) algorithm is applied to encrypt tag IDs and protect patients' privacy. Here, and in other similar systems, opportunistic networks can easily find applicability. As seen, patients with dementia are generally monitored in terms of changes in their behavior (i.e., alerts are sent if the patient forgets his whereabouts).

Opportunistic networking brings an interesting evolution of the multi-hop networking paradigm. With ONs, node mobility is not a problem anymore, but rather an opportunity to be exploited. In this case, the mobility of nodes creates contact opportunities among nodes, which can be used to connect parts of the network that are otherwise disconnected. Dementia patient monitoring is one case study where ONs can be easily integrated with other health monitoring techniques. ONs can offer support for alerting people in the location-based proximity when a patient deviates from his normal path and is potentially lost (i.e., in a hospital, the nearby nurse could be more easily alerted by an opportunistically-disseminated message, if the dementia-suffering patient exits a particular critical zone). WSNs can still be used for disseminating life-critical messages (and, even better, they can be extended with capabilities for short-time delay tolerance to better cope with the loss of transmission path, for example), but for collecting information about the state-of-mind and habits of patients, we believe ONs to be perfect candidates. Wireless patient monitoring and mobile healthcare can benefit a lot from this. Inside the house, the dementia-suffering patient can be conditioned through external stimuli to remember doing a specific activity (i.e., through turning a light bulb on, or starting the TV, ringing the doorbell, etc.). Outside, a GPS-enabled device carried by the patient can prevent him from being lost (i.e., by monitoring the patient's activity and location, and triggering automatic alarms when he deviates far from his usual routine), or support him by triggering memory reactions through specific stimuli (e.g., triggering a specific alarm or small voltage on the device the user is carrying around his wrist). For such applications, ad-hoc networking techniques can provide the necessary technological base and support.

4. A DEMENTIA PATIENT MONITORING SYSTEM USING OPPORTUNISTIC NETWORKS

Living assistance systems focusing on the support of dementia-suffering patients in their own environments are generally referred to as patient-care systems. Elderly people, in particular, have a high risk of suffering from typical high-age diseases, dementia (including Alzheimer’s) being one of them. The costs of providing care for this population increases with a decreasing age-dependency ratio defined by the number of working individuals divided by the number of handicapped people of a country. Experts predict this ratio will dramatically approach 1 in the next 10 to 20 years. Thus, it is obvious that society has to react somehow to this dramatic process. Therefore, innovative solutions for living assistance systems must be envisioned in order to cope with this development. Automated patient-care systems based on ambient intelligence technology are a promising approach. They aim at the prolongation of a self-conducted life of assisted persons, reducing the dependency on intensive personal care to a minimum and thereby increasing the quality of life for the affected group while substantially decreasing the costs for society.

The ultimate goals of any patient monitoring system are high recall in detecting every real emergency immediately, and high precision, to prevent invalid emergency detections and alerts as a consequence of misinterpretations. The first requirement is mandatory to provide a trustworthy service quality to the affected persons in case of emergency situations that should be much safer than anything else they experienced before. The second requirement is essential for economic reasons, since invalid emergency alerts may unacceptably increase care costs and decrease trustworthiness. It is highly desirable to extend a pure emergency detection service by an emergency prediction service, which attempts to recognize a critical health condition before it escalates into an emergency. As a reaction to the detection of such critical situations, the service may assist the person in preventing the emergency, e.g., by suggesting appropriate medication.

Generally, memory has been an extensively studied topic in psychology, cognitive sciences and biology. Of course, regarding the process of passing information from short-term memory into long-term memory, we can say that it is a very complex one that requires a high amount of energy from a person, being a stress factor in the cognitive level.

Migliardi et al. performed a study on efficient software on smart devices and how they influence the short and long-term memory (Migliardi & Gaudina, 2011), and concluded that the system developed by them, in which some sensors that vibrated were placed on a jacket, improves memory and prevents user frustration that comes from the inability to remember the time and place in which they communicated. Another important discovery made by the authors is that the communication through the use of a vibrant jacket does not distract from the important things and does not phonically affect the environment. Regarding the dynamics of today's technology and all stimuli which one faces in daily life, implementing techniques to improve memory has become a necessary way for man to be able to function at full capacity anytime anywhere. The development of the robotics industries in the last 25 years has seen a remarkable progress. Although industrialization has brought upon the streamlining of productivity and quality, the human factor had a significant decline as these technologies are quite advanced for workers who until recent years used to work manually. Based on this problem, the software technology and robotic equipment developers focus on the human factor problem.

Improving the lives of people who have memory problems can be done by designing systems to assist them in daily activities. To do this, these systems need to study and analyze the life context of people to see what kind of problems occurs because of memory. The quality of life of older people can be improved by using new technologies. Wireless technology and the increasing computational power have brought upon new solutions for health monitoring systems in real-time (real-time monitoring). Lindeberg et al. (2010) state that users of such techniques, like patients or medical staff, enjoy two advantages. Firstly, wireless technology reduces the number of cables involved in the monitoring system, resulting in a better mobility of patients within the hospital. Moreover, wireless technology may collect data from sensors connected to the patient's body, while they are at home or in places where cables would prevent this possibility. The second advantage is that wireless systems allow data collection and processing at any time. Older people should get accustomed with an active lifestyle. This requires strategies to improve the quality of their life. They must participate in society through citizen initiatives in which they use their time, experience and energy in various organizations.

Active participation of the elderly people in society can bring economic and social benefits to society through activities that older people do and the opportunities they create as workers or volunteers. Also, the motivation and usefulness feeling of elderly people can be maintained and enhanced, thus avoiding the risk of social isolation and many of the risks associated with this. Elderly people face many obstacles in trying to still be active in society. They are often faced with restricted access to certain social, political or infrastructure activities. The results of these limitations are observed by their inability to keep up with technology, lack of information, few social communities and low self-esteem. Local authorities play an important role in the process of keeping the elderly involved in society. The authorities should create and promote social inclusion programs for seniors. Examples of such programs are: senior volunteering, active citizenship, social networks.

In today's society there was a simultaneous increase of elderly population and technology development (Bouwhuis et al, 2007). Among the goals of technology, solving the problems that society is facing is one of the most important. The new assistance systems that technology provides enable elderly people to be independent, thereby enhancing their quality of life. Society relies increasingly on technology, so the need to use ICT always increases. Therefore, these systems must be constructed so as to demonstrate ergonomics and be intuitive and easy to use by seniors.

Although those who design new technological systems have this in mind, the elderly often face problems when choosing to use technology due to the increased complexity that characterizes new technologies. Caprani et al. (2012) believe that, in order to prevent and mitigate this aspect, it is necessary to conduct research aimed at ways of understanding the lifestyle of the elderly, the way they use technology and how to build new systems and devices that can be more easily used by them.

One way to find these things is provided in (Caprani et al, 2012), and consists of using a questionnaire to collect data on elderly people's attitudes about technology and about how they use technology. The questionnaire also investigates where elders use technology, how often they use it, as well as lifestyle issues that prevent their access to technology. Therefore, in designing new technological products, experts must take into account the available information about the elderly, so that future products can be used by them, thereby helping improve the lives of older people.

Emphasis on video and audio sensing technology allows the development of a new branch of technology, the smart home systems and automated home care. This system is based on recording and reading information collected from sensors that are placed in the house. Søberg et al. (2010) state that data obtained from the sensors is processed through CEP (complex event processing). The concept of smart homes based on sensors can be useful especially for the elderly. For old people it can be a significant improvement in the quality of life, by reducing the effort that they have to submit in performing certain daily activities requiring a significant amount of energy on their part. However, the challenge for the designers of these types of sensor systems is to take into account the difficulties faced by the elderly in the use of technology. Thus, given the complexity of such a system, it may seem difficult to understand and use even by persons for whom technology is an important part of life and moreso for the elderly.

Considering this aspect, the systems must include a user-friendly and easy to access interface for any group of people and show increased ergonomics. Besides, the design of such systems must take into account the needs that older people have, given that they may represent an important segment of the population that will use sensor systems and the concept of smart homes. Søberg et al. (2010) created such a sensor system for homes, which they named CommonSens. Their solution introduces a complex event processing system for automated home care, that provides personalization between core concepts like Locations of Interest (LoIs - a set of coordinates describing the boundaries of an interesting location in the environment) and the monitored persons at home through complex event processing. Such awareness applications have received significant attention from researchers lately. Most of them were extruded on studying the improvement of human functioning in some contexts and difficult environmental situations by increasing the state of awareness with the help of computers. With CommonSens, the improvement in the memory of elderly people was tested by designing an application which receives verbal commands regarding the needs of people, translating those needs into queries to a GIS and building a map of the locations where these needs can be satisfied when the environment in which the person exists allows this.

This system is based on three separate models: an identifier model that monitors events and state changes that occur in the home environment and are of interest, a model that describes the physical and logical sensors possibilities, the coverage they have and the type of used signal, and an environment model that describes the physical environment and the impact that it has on the signal. What is new compared to the existing systems is the ability to identify events that indicate that something is not right. This ability is called deviation detection and is based on lists of words and phrases that are entered into the software that can notify contacts when one signals that something is not right. The system perceives the existence of a problem, and emergency contacts are announced. An advantage of the system is that it does not come with a standard list of problematic events, leaving them to be implemented by the user. Thus, each user can create their own list of possible problems that may occur depending on the difficulties that one may face.

The CommonSens system may be beneficial in increasing the safety of any person. But, if we consider the difficulties faced by the elderly, we believe that CommonSens is the biggest help for them. Such a system is especially necessary for people who live alone when something happens in their own homes. In such a situation, a sensor monitoring program instantly contacts the designated contact person. Thus, one can avoid unpleasant events, especially regarding older people who are usually more exposed to risk than the general population.

Chernbumroong identified three major features that a support sensor system has to meet so as to be considered optimum for the elderly (Chernbumroong et al, 2013): high level of acceptance (the system must be environmental and discreet), high degree of adaptation (the system must be able to adapt to situational changes or possible changes of the elderly so as to serve their needs), and ease of use (the system must be in an accessible form so as to be easily used by the user)

The Social Care Institute for Excellence discussed the usefulness of information and communication technology (ICT) in helping and supporting people with dementia (Ciobanu et al, 2014). It is known that among the problems faced by people with dementia, communication problems are very often encountered. Computers (PCs, laptops, smartphones), the Internet and the digital world (audio, photo, video) can stimulate and improve the lives of sufferers. Activities which include ICT in the lives of people with dementia should be conducted in appropriate frameworks and adequate staff should be used so as to maintain the safety of persons. Thus, the realization of a high quality dementia monitoring system requires a sound model of the assisted people, which has a precise notion for critical situations and emergency cases. Such a model must allow personalizing the service, i.e., customizing it by taking into account the existing memory problems associated with each person. The idea of such a model is illustrated in Figure 1.

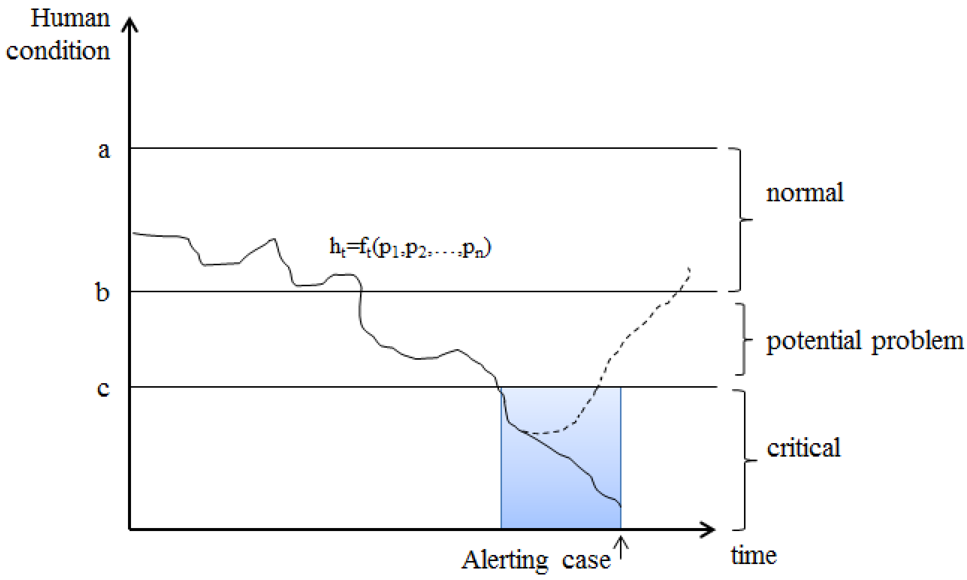


Figure 1. A condition-monitoring patient model.

Figure 1 shows several intervals: the first one defines the normal parameters for good living conditions for a monitored patient, the second one defines boundaries of living conditions, considering the particular person's memory condition, and the last one defines the borderline between normal and critical health conditions. This model is similar to the Event Model proposed in CommonSens. Considering the existing memory impairments of a person, it is mandatory for any monitoring system related to catastrophic events (e.g., a person is lost in a park) to recognize boundary conditions in order to prevent misinterpretation of situations. This can be used to cope with situations where a person deviates from the usual route because of a municipality-operated scheduled detour (e.g., maintenance work to replace an underground pipe in the park), which otherwise might be wrongly recognized as a catastrophic event (i.e., alerting units of potential lost person in the park). Also, the context parameters could be used to formulate user-centric boundaries, considering personalized health conditions. For instance, a person with locomotor disturbance will move slower than a person who does not suffer from this disability. Slow movement of such a person must again not be misinterpreted as a critical situation resulting in a false emergency alert.

The fictive curve in Figure 1 defines the overall condition of a monitored person as a function over time. The function depends on a large, unknown number of parameters and is virtually impossible to describe in a precise mathematical sense. The ultimate goal of any patient monitoring system is to detect the entering of the shadowed area in Figure 1. In such a case, the monitoring system must undertake all possible actions to prevent the emergency (e.g., if the person is detected as having a heart stroke, the system might use animations to remind the patient of medication, drinking, etc.), thereby bringing the health and status condition of the person back to normal (i.e., the dotted line).

An approximation of this model may be achieved by continuously acquiring data about a person's body functions such as temperature, blood pressure, and pulse frequency, together with data on his short-term, medium-term and long-term behavior (including tracking the person in space and time). This data is then evaluated and condensed. Logical predicates (called situations) can be further used to identify states or state transitions of the person under observation. Examples for such situations are: “Person X forgot to take medicine M”, “Person X has fallen down” or “Person X has a blood pressure of 178”. Several situations may also be combined in logical expressions, resulting in more complex situations, as in "(Person X has fallen down) AND (Person X forgot to take medicine M) AND (Person X has not responded to call for S seconds)". If such a critical situation occurs, it is taken as evidence that a person's health condition has entered the shadowed region in Figure 1, which now requires appropriate system actions.

The patient monitoring system thus operates by evaluating each situation individually. Whenever the system moves from situation s_i to s_{i+1}, the evaluation cycle is triggered, taking the logical predicates of the actual situation as input for the test against the critical situation indicators in the database. If one or more critical situation indicators are evaluated to be true, a critical situation is concluded and the appropriate system action is initiated.

It is obvious that any living assistance system in the described domain will fail if it requires special skills by the monitored patients for using and handling it. Instead, the assistance system should be completely invisible to those persons. This also means that the physical condition of the assisted person has to be sensed in an unobtrusive manner. Environmental sensors must be preferred to sensors directly attached to the body, even if this results in a lower precision of the measured values. The system has to compensate this by taking several environmental measurements into account and drawing conclusions from them. This is, of course, a challenging task, but this is the way monitored systems should work.

Based on the identified situations, the system should operate proactively and do its job automatically with minimal human intervention. It would interact with humans by speech, gestures, and other forms of natural communication. It would provide its service in a stable, robust and reliable way, even in the presence of component malfunctions, power/battery breakdown, or other exceptional conditions. Software release changes and maintenance actions will be performed remotely without interrupting the system operation and with minimal intervention by maintenance personnel.

We present a patient monitoring system composed of several subsystems (see Figure 2): the body area network (BAN), the home network, and the central processing node, which also acts as a gateway to the Internet and other external services like the telephone network. We assume sensors, computing devices and actuators are used to provide memory impairment support services for the patients. Sensors can also be used to (semi-) automatically collect data about the lifestyle of the subjects. As specified before, this can enrich the data collected in the traditional way (i.e., currently the health/mental status for the dementia patients is monitored mostly through interviews and observation).

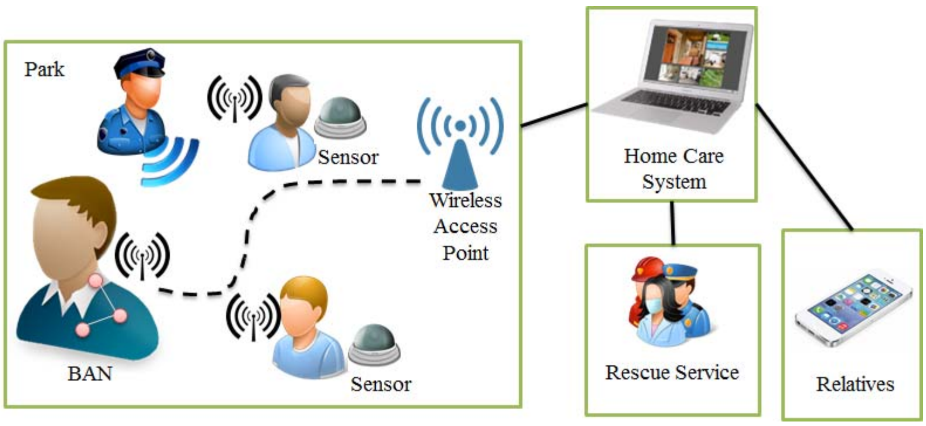


Figure 2. The patient monitoring system.

The body area network is composed of special sensors that monitor vital body functions like blood pressure, temperature, pulse frequency, etc., together with location, acceleration and other environmental parameters, and transmit their results via a wireless connection. The body network is invisibly embedded in clothes, in watches and glasses, so that the patient does not have to put on those sensors explicitly. In fact, they should not even be aware that sensors exist. The system collects the measurements from the different sensors, on-body and also external sensors where available (i.e., for indoors, located inside the house, and for outdoors, possibly provided by persons in the wireless proximity), aggregates the provided sensing data, and periodically transmits it toward a central station for further processing. When there is a direct Internet connection, this will be the preferred means to transmit the data. For indoor scenarios, it is more likely that a wired connection is available. However, things are different for outdoor scenarios. Consider the patient walking around the park. In the absence of an all-available Internet connection, the system might use ad-hoc networking alternatives to send the data to the Wireless Access Point provided inside the park by the municipality. Here, we employ the use of opportunistic networking techniques. These techniques will be used to also collect sensing data from the environment. For example, while the patient is walking by, he can connect to other mobile devices, carried by other people, and collect valuable sensing data (e.g., location data can be used to certify the whereabouts of the user). The nearby devices are also able to track the patient, so when they are placed together, rescuers can use the tracking data to reconstruct the path followed by the dementia patient. Thus, the monitoring system uses opportunistic networking to connect to nearby devices for at least two causes: support for communication, and support for human tracking and sensor data sharing. Last but not least, when a critical event occurs, the Home Care System can use opportunistic dissemination to send an alert message to people walking in the park (i.e., for asking about the whereabouts of the patient, for finding him, or for sending request for assistance messages, such as “please remind this person, if you see him, to take the medication”).

The home network is particularly useful to monitor the patient indoors, and it consists of sensors attached to walls in rooms and their equipment for collecting data about the behavior of the person under observation. Part of the home network might also include loudspeakers, microphones, and video cameras for communicating with the person. It is assumed that video cameras are usually switched off, and they will be activated only after the detection of an emergency, in order to provide external medical personnel the option of looking at the person. This constraint guarantees privacy for the persons under observation.

For the outdoor living assistance, the monitoring system may acquire additional context information that describes unforeseen situations (traffic jams, etc.). Of course, for outdoor living assistance, the monitoring systems may never rely on a stable communication infrastructure, i.e., the quality (bandwidth, transmission delay, etc.) and the reachability of services may dynamically change by orders of magnitude. For tracking, in particular, opportunistic networking techniques described next can provide valuable monitoring applications.

Since full wireless coverage is not easy to find at all times in outdoor environments, network communications can be inevitably intermittent and thus very challenging. To overcome this difficulty, we propose applying a delay/disruption-tolerant network technique to tracking patients, making use of opportunistic, ad-hoc, and short-range wireless communications to disseminate data over the network in a store-carry-and-forward fashion. More precisely, each patient is required to carry a device with a GPS receiver, a Zigbee (or other short- or medium-range) wireless radio. When patients encounter other persons on their trails, their BAN motes (see Figure 2) automatically exchange their IDs and record the encounter information (i.e., the time and location) in their respective memories. The devices continue exchanging their stored data as long as possible (i.e., depending on the encounter time and the wireless bandwidth). Then, when a patient reaches one of the base-stations installed at frequently visited spots in the park, all the information stored in his device is uploaded to an Internet server from the base station via GPRS or Wi-Fi.

An important concern that arises regarding a system such as the one we propose here is related to privacy. Since opportunistic networking uses encountered nodes as relays for data, privacy must be ensured so that the collected data cannot be read by anyone except the intended recipient. Thus, a node that carries a data object for another node must not be able to decipher it for its own personal use. Private sensitive information such as social security number, medical records, or current geographical position might be contained in such a data object, so it is of the utmost importance that the proposed system doesn't permit malicious nodes to read and use the data. For this reason, we propose using an asymmetric cryptography mechanism. This way, the medical facility (i.e., hospital, medical ward, etc.) that a patient is associated with has a pair of public and private keys. Data generated by the patient's BAN and various other sensors is encrypted with the corresponding public key, since it is only of use and relevance to the medical facility. When the data is uploaded to the facility (using a wireless access point or opportunistic contacts), it can be decrypted with the public key and analyzed accordingly. Less sensitive information (that might be used to assess the current condition of the patient in more general terms) does not necessarily have to be encrypted, since it might be used to signal an alarm that something is wrong. This is the type of decision that should be taken as soon as possible, i.e., even before the aggregated data reaches the medical facility. As an example, if the patient's sensors show abnormal conditions in the patient's vital signs, the data should be interpreted by any node that can do so, in order to alert the necessary entities (i.e., an ambulance, the police, etc.) that can respond to the emergency in a timely fashion.

Even if messages might, hypothetically, be still compromised, privacy is further enforced by the fact that a communication can be decomposed into several messages, each traveling on a completely different path to its destination. Given its specifics, in an opportunistic network between any two nodes messages can, in fact, travel on completely different paths, making the process of capturing messages belonging to one single session an impossible task.

It is also important to address the issue of opportunistic network reliability. Since ONs do not assume the existence of paths between nodes (instead relying on contacts), a path between two nodes might simply not exist, so these two nodes will never be connected and/or able to communicate. Thus, minimum requirements regarding the number of nodes running the system proposed here should be set and enforced if possible. There are various factors that should be taken into account in order to define these requirements. For example, the wireless communication distance of each node should be considered (it depends on the wireless communication protocols assumed), since it specifies how close two nodes must be in order to exchange information. Moreover, the closer two nodes are, the stronger the wireless signal between them is, so the density of the opportunistic network is also an important factor. This has to be balanced against the problem of channel interference: since wireless communication uses air media, there is a huge possibility of having more than one communicating pair within one-hop range, leading to possible congestion at medium access control. Reliability should also be ensured, but this only happens if the correct carriers are selected at each step (but, as we show later on, flooding the network with all the messages is not feasible, since it leads to congestion and messages being dropped). The system we propose assumes the existence of wireless access points where the dementia patient roams (e.g., a park), so requirements might be addressed to the municipality to ensure that these are in place according to predefined distances. Moreover, since the system proposed here might have to deal with emergency situations, it is able to use cellular networks when such situations arise, ensuring another degree of reliability (through the WSN layer, as previously shown).

5. OPPORTUNISTIC ALGORITHMS FOR THE PROPOSED FRAMEWORK

The dementia patient monitoring framework proposed above can be used with various ON-specific algorithms at the data transfer level, depending on the requirements. For example, if certain data should be spread to all the nodes in the ON (such as information about the timely location of a patient walking in the park), then a dissemination algorithm should be employed. If, on the other hand, a node wants to send a message to a specific node (e.g., a monitoring system needs to notify a doctor or a caretaker that they need to attend to a certain patient), then a routing algorithm should be used, which opportunistically moves the message node by node until it reaches the intended destination.

In this Section, we present a dissemination and a routing algorithm that we have previously proposed, and which can be employed in the dementia patient monitoring system presented in Section IV. We also explain why we believe that our solutions can be successfully employed. In Section VI, we show the results obtained when running our algorithms in simulations based on existing mobility traces.

SPRINT: Opportunistic Routing

SPRINT (Social PRedIction-based routing in opportunistic NeTworks) (Ciobanu et al, 2013) is an opportunistic routing algorithm that combines socially-aware routing, including both learned and offline social information about nodes, with a module capable to predict node behavior. Its purpose is to improve the hit rate (i.e., number of messages that successfully reach their destinations) when compared to other algorithms, while also keeping the overhead and delivery latency as low as possible. It is based on the knowledge (proven in Ciobanu & Dobre, 2012) that opportunistic nodes belonging to humans are inherently predictable, since the behavior of their owners is predictable. If we are talking about a situation such as a hospital wing, this is even truer, since doctors and nurses generally follow the same mobility patterns daily, while doing their rounds and visiting the patients they are responsible of. The social aspect assumes that nodes have previous information regarding the social connection between nodes, such as online social network friendship (e.g., Facebook or Google+). When talking about (for example) a hospital or medical care environment, we believe it is better to group nodes socially based on the function and rank of each node in the ON. Thus, nodes may be first and foremost split into patients and medical staff, each belonging to their own social community. Inside communities, nodes might also be split according to various other criteria, such as nurses and doctors, patients with severe disorders and patients with lesser disorders, etc. In a situation similar to what we have presented in Section IV, the nodes might be split according to the relationship with the monitored patient (for example, family members that visit daily should be socially connected to the patient). These social communities are then used in improving the prediction mechanism of the SPRINT algorithm, since nodes that belong to the same community tend to meet each other more often (e.g., nurses have a higher chance of meeting each other than they do of meeting a doctor). Moreover, connections between members of different communities can also be created. For example, a doctor would be socially connected to all the patients in his care, since they interact on a regular basis.

The memory of a node running SPRINT is split into two sections: a data memory and a cache memory. The former is used to store data objects (which have either been generated by the current node, or are just being stored and carried for future forwarding), while the cache memory contains information about the node's previous encounters with other participants in the network. When two nodes meet, they exchange information about each message in their data memory, based on which each node computes utility values for the messages in its own memory, as well as for the ones advertised by the encountered node. It then sorts them according to their utility values. If some of the messages with high utility values belong to the encountered node, a download request is sent for each of them. The node then starts transferring these messages in utility order, until it has finished downloading all the required messages or the two encountering nodes are not in range anymore. Thus, the formula used by a SPRINT node A to compute the utility of a message M is:

$$u(M,A) = w_1 \times U_1(M,A) + w_2 \times U_2(M,A)$$

$u(M,A)$ is the utility of message M as computed by node A, while w_1 and w_2 are weight values which follow the conditions that $w_1 + w_2 = 1$ and $w_1 > w_2$. U_1 and U_2 are utility components computed according to the following formulas:

$$U_1(M,A) = freshness(M) + p(M,A) \times (1 - \frac{enc(M,A)}{24})$$

$$U_2(M,A) = c_e(M,A) \times \frac{s_n(M) + hop(M) + pop(A) + time(M,A)}{4}$$

Since we want the newly-generated messages to start traveling through the opportunistic network as fast as possible, the $freshness(M)$ component favors new messages. The value is set to 0.5 if the message has been created less than a day ago, and to 0 otherwise. This means that in the beginning, when new messages are created, they are spread to several nodes (the utility value is high). As messages travel along the network, they are forwarded only to other nodes that maximize the changes of successful delivery.

$p(M,A)$ is the probability of node A being able to deliver a message M closer to its destination. The term is based on predicting a node's behavior, combined with the idea that a node has a higher chance of interacting with nodes it is socially connected with and/or has encountered before. It is an environment-specific function that can be configured according to the contact distribution of the network SPRINT is used in. For the environments we are testing with, we compute it based on the assumption that the node contacts follow a Poisson distribution. We have shown this to be true for academic environments, but we also believe the results stand for medical environments, since the members of a hospital generally have fixed schedules and follow the same movement patterns daily. A prediction is thus made using the Poisson distribution and social knowledge, and the first N nodes in the order of encounter probability are picked as potential future contacts. This is done for each of the next 24 hours (sorted by probability), while for the rest of the nodes, $p(M,A)$ is set to 0.

U_1 also uses $enc(M,A)$, which is the hour of the day when the destination of message M will be met according to the probabilities previously computed. If the destination will never be encountered, then $enc(M,A)$ is set to 24 (so the product is 0). We multiply $p(M,A)$ by $1-\frac{enc(M,A)}{24}$ because the sooner a good target for a message is met, the sooner the node can delete the message from its memory and have room for others.

The second component of the utility function is U_2. Its first member - $c_e(M,A)$ - is set to 1 if node A is in the same community as the destination of message M or if node A will ever encounter a node that has a social relationship with M, and 0 otherwise. Again, the prediction information computed for U_1 is used to analyze the potential future encounters of a node.

The $s_n(M)$ component is set to 1 if the source and destination of M do not have a social connection, because if a message does not have the source and destination in the same community, the chance of it being delivered by the source is low since it will mostly meet nodes belonging to its own community. Therefore, the messages should be given to a different node that has the chance of reaching the destination community. If M's source and destination are in the same community, $s_n(M)$ is 0.

$hop(M)$ represents the normalized number of nodes that M has visited, $pop(A)$ is the normalized popularity value of A according to its social network information (i.e., number of friends in the opportunistic network), and finally $time(M,A)$ is the total time spent by node A in contact with M's destination. The $hop(M)$ and $time(M,A)$ values are used because nodes should travel as little as possible before reaching their destination.

ONSIDE: Opportunistic Dissemination

ONSIDE (OpportuNistic Socially-aware and Interest-based DissEmination) (Ciobanu et al, 2014) is a publish/subscribe-based algorithm that disseminates data in opportunistic networks based on nodes' interests, together with social information about the nodes in the ON. Its goal is to reduce the overhead of spreading the data, while not affecting the hit rate and the delivery latency.

It is based on several assumptions, the first of them being that nodes which have common interests tend to meet each other more often than nodes that do not. The second assumption that ONSIDE is based on is similar to SPRINT's condition that connections from online social networks are valid in an ON node’s encounters. Not only do nodes tend to encounter socially connected neighbors more often, but there is also a high chance that a node encounters a second-degree neighbor (i.e., a node that it has at least one friend in common with).

The functionality of ONSIDE when two nodes meet is very similar to SPRINT's, the main difference being the way the utility of a message is computed. Thus, the function used by a node A to analyze a message M from a node B and to decide whether it should be downloaded is:

$$\begin{aligned} Exchange(A,B,M) = {} & (CommonInterests(A,B) \geq 1) \\ & \& Interested(A, M.topic) \\ & \& (InterestedFriends(A, M.topic) \geq thr_f) \\ & \& (InterestsEncountered(A, M.topic) \geq thr_i) \end{aligned}$$

The result of the *Exchange* function is a boolean value that specifies whether a download request should be made to B for message M. The *CommonInterests* function returns the number of topics that both A and B are interested in. This way, data transfers are only performed between nodes with at least one common interest, based on the previous assumption that these nodes encounter each other often and are thus able to successfully deliver channel data to all subscribed nodes.

The second component of the *Exchange* function is *Interested* , which returns true if node A is subscribed to the channel that generated message M (i.e., if it is interested in M's topic). By using this function, a node will not only download a message for itself and then drop it after use, but will also store it for others, since it is highly likely to encounter other nodes that have similar interests to its own.

The *InterestedFriends* function returns the number of online social network friends of node A that are subscribed to the channel that generated M. By using this component, we assume that a node has access to its social network at any time, which contains at least interest information about the connected nodes. This component has the role of further reducing the amount of messages exchanged in the network, by only requesting a message if a node's social network friends (i.e., nodes that it has a high chance of encountering) are also interested in it. This not only reduces the congestion, but also has the role of speeding up the message's delivery. thr_f is a threshold that can be varied according to the density of the ON and of the social network.

Finally, the last component of the *Exchange* function, *InterestsEncountered* , is computed based on node A's history of encounters. It returns the percentage of encounters with nodes that are interested in messages similar to M, in terms of channel subscriptions. This function is based on the assumption that a node's behavior in an ON is predictable, so that if it encountered many nodes subscribed to a certain channel, it is likely to encounter others in the future as well. thr_i is a threshold between 0 and 1 that can be varied depending on the number of channels in the ON.

When talking about channels and subscriptions in a dementia patient monitoring environment, we envision various sources of information, both for the medical staff, as well as for the patients. Each node subscribes to the channel it is interested in, such as doctors and nurses for feeds regarding the status of certain patients, or said patients for channels that publish information about the visiting hours for the ward they are in, etc. Thus, nodes that are subscribed to the same channel (like a nurse and a doctor that take care of a specific patient) have a higher chance of encountering each other than two nodes without common interests (such as two nurses working in different wards). Similarly, for the solution proposed in Section IV, we envision that proximity police officers subscribe to information generated by the known dementia patients located in their assigned area. This way, they can be notified whenever an alert generated by the sensors that belong to the patient's BAN signal a potential problem, and may thus respond in a timely fashion. Consequently, ONSIDE takes advantage of subscription information to reduce the quantity of messages exchanged in the ON, which leads to a quicker and more efficient delivery.

6. EVALUATION OF OPPORTUNISTIC NETWORKS AS A RELIABLE INFRASTRUCTURE

When employing opportunistic networks for dementia patient monitoring, we need to ensure that the underlying algorithms are viable for the environment where they are being applied. Since ONs are based on contacts between nodes, it is relatively difficult to employ ONs in sparse networks, since there are few nodes and thus the encounters between nodes are rare. However, in a situation such as the one we described in Section IV, there are many nodes spread on a small surface, so both the number of contacts, as well as ON nodes, are high. Thus, there are many opportunities for data to be exchanged, leading to high hit rates. However, in such a situation there may appear node congestion, especially if there are many messages in the network, and if the nodes have low data memories. For this reason, the algorithms employed should be able to reduce congestion by carefully selecting the next hop at each step.

In this Section, we present the results obtained by running SPRINT and ONSIDE on several well-known mobility traces using the MobEmu emulator (Ciobanu et al, 2012). Most of the traces used were taken in academic environments, but we believe that a medical environment is similar: the contacts are many and occur often, during a short time span. The traces we tested with are UPB 2011 (Ciobanu et al, 2012), UPB 2012 (Marin et al, 2012), St. Andrews (Bigwood et al, 2008), Content (Scott et al, 2006), Infocom 2006 (Hui & Crowcroft, 2007) and Sigcomm 2009 (Pietilainen et al, 2009). We tried to select traces for various environments, which contained the information needed for the deployment of our solutions (such as social and interest information).

The first metric we analyze is hit rate, defined as the ratio between successfully delivered messages and the total number of generated messages. Next, the delivery latency is defined as the time passed between the generation of a message and its eventual delivery to the destination. Another metric we use is the delivery cost, defined as the ratio between the total number of messages exchanged during the course of the test and the number of generated messages, which shows the congestion of the network. Finally, the hop count is the number of nodes that carried a message until it reached the destination on the shortest path, and should be as low as possible in order to avoid node congestion.

SPRINT

When presenting the results obtained by SPRINT on the mobility traces, we compare it to BUBBLE Rap (Hui et al, 2008), which is one of the most efficient and well-known data dissemination algorithms for ONs. Furthermore, we also compare SPRINT to the Epidemic routing algorithm (Vahdat & Becker, 2006), which is a simple but impractical algorithm that we use in order to find out the maximum possible hit rate that can be achieved in our tests. When two nodes running Epidemic routing meet, they simply download all the messages from each other, so a maximum hit rate is surely to be achieved. However, this happens at the expense of storage space, and in a large real-life network it would be impossible to implement such an algorithm since the data memory required would be extremely large. We only use the hit rate data obtained by Epidemic, since it is the only information relevant to us.

Additional information about the experimental setup and a thorough analysis of the results obtained by running SPRINT can be found in (Ciobanu et al, 2013). Here we present a summary of the results, in order to show that SPRINT is a viable option for the system presented in Section IV.

Figure 3 shows the results obtained when running SPRINT, Epidemic and BUBBLE Rap on the UPB 2011 trace. It can be seen that the hit rate for SPRINT is better than the hit rate obtained by BUBBLE Rap for most of the cases. The figure shows that SPRINT can achieve maximum hit rate, whereas BUBBLE Rap cannot, even for a data memory of 4500 messages.

Other improvements brought by SPRINT can be seen when looking at the delivery cost and average hop count charts, where SPRINT outperforms BUBBLE Rap as well. Finally, SPRINT manages to improve latency by up to seven hours, which can prove to be the difference between life and death in certain situations. The situation is similar for UPB 2012, as the traces were performed in similar conditions.

Another trace where SPRINT uses contact prediction when performing routing decisions is St. Andrews, and results are shown in Figure 4. This time, SPRINT does not manage to achieve maximum hit rate. Nonetheless, SPRINT's hit rate is better than BUBBLE Rap's, irrespective of the data memory size. The delivery cost and average hop count situation is similar to the one observed at UPB 2012: for small data memory values, they are improved. However, because a larger data memory helps the algorithm distribute more messages to remote nodes, the overall delivery cost and hop count are increased. For large data memory values, SPRINT improves the average latency.

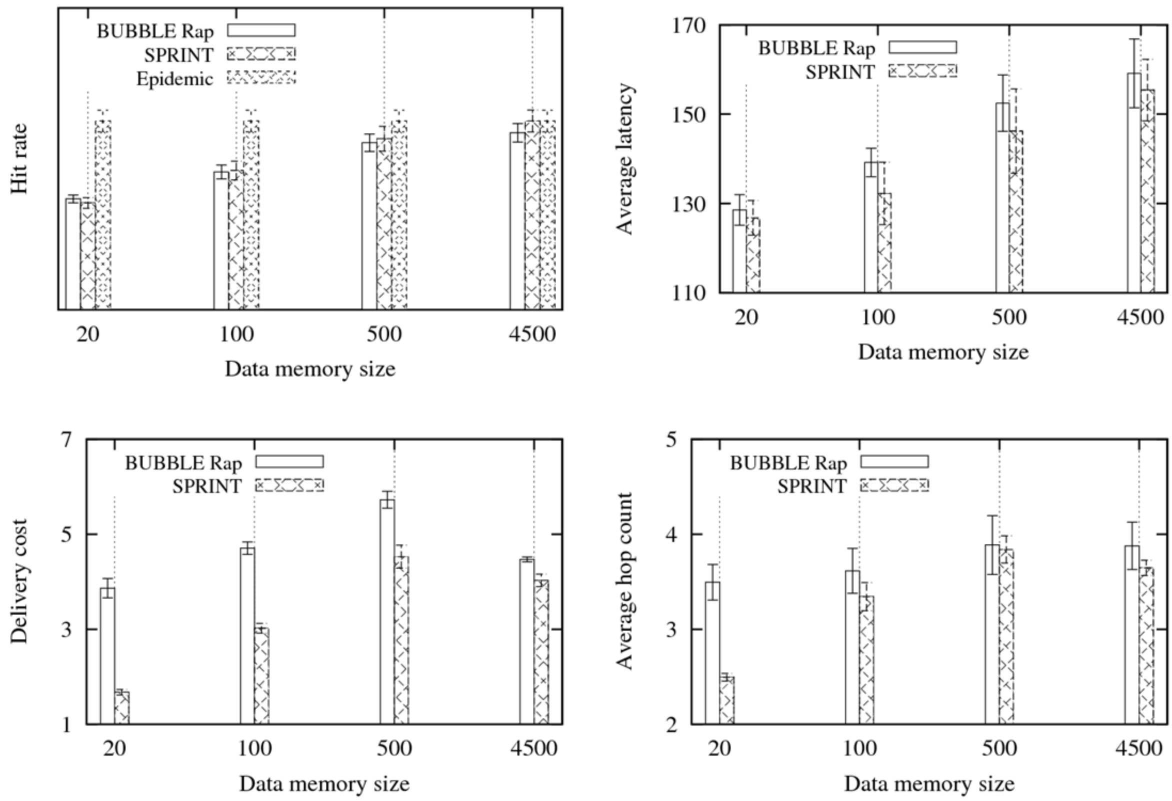


Figure 3. SPRINT results for UPB 2011.

Although Content and Infocom 2006 do not contain social information and the U_1 component of a message's utility for SPRINT is 0, our proposed algorithm still behaves well, as it still uses social and context information to assign utility values to messages.

Figure 5 shows the results for Content and it can be seen that, although SPRINT does not manage to achieve maximum hit rate (because it lacks the prediction component), it still outperforms BUBBLE Rap in terms of hit rate by as much as 3%. However, the important results for this trace concern congestion, namely delivery cost and average hop count. SPRINT manages to decrease the delivery cost by as much as 146, so the total number of messages exchanged in the ON is five times lower when using SPRINT. The hop count is also reduced dramatically by SPRINT. Most importantly, delivery latency is also decreased by as much as 8 hours when using SPRINT. The Infocom 2006 results look very much alike to what was obtained for Content: SPRINT outperforms BUBBLE Rap in terms of hit rate, delivery cost, hop count, as well as average latency.

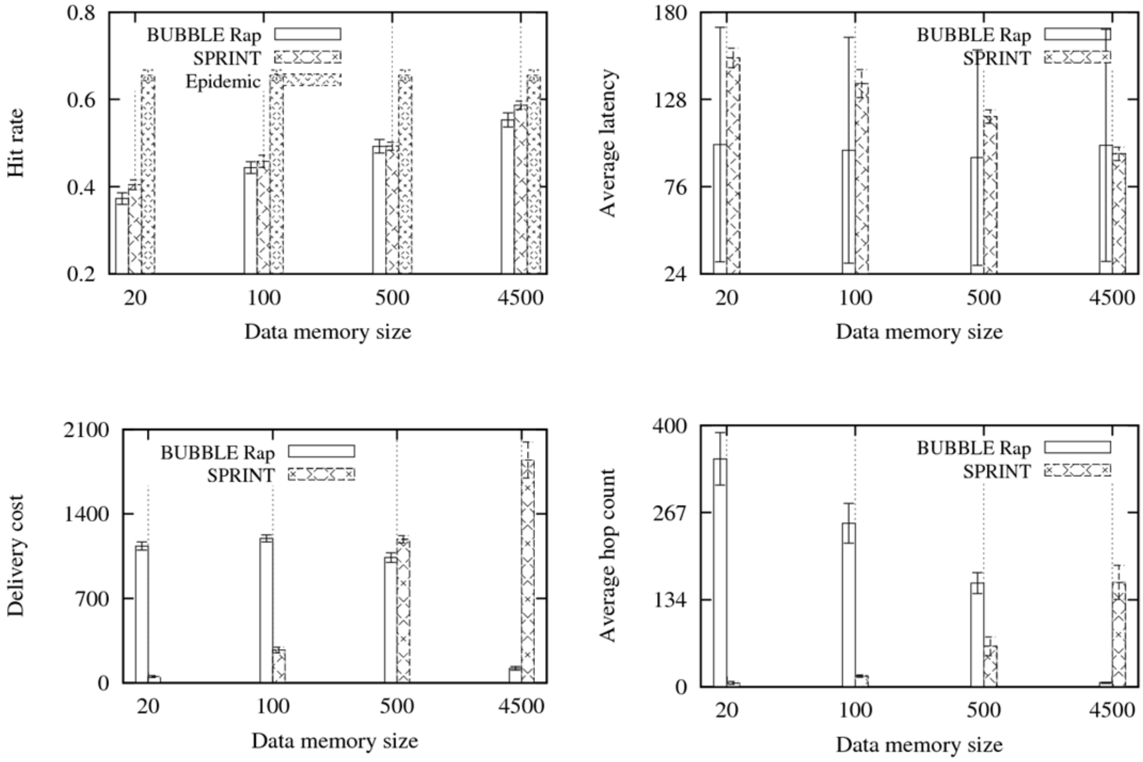


Figure 4. SPRINT results for St. Andrews.

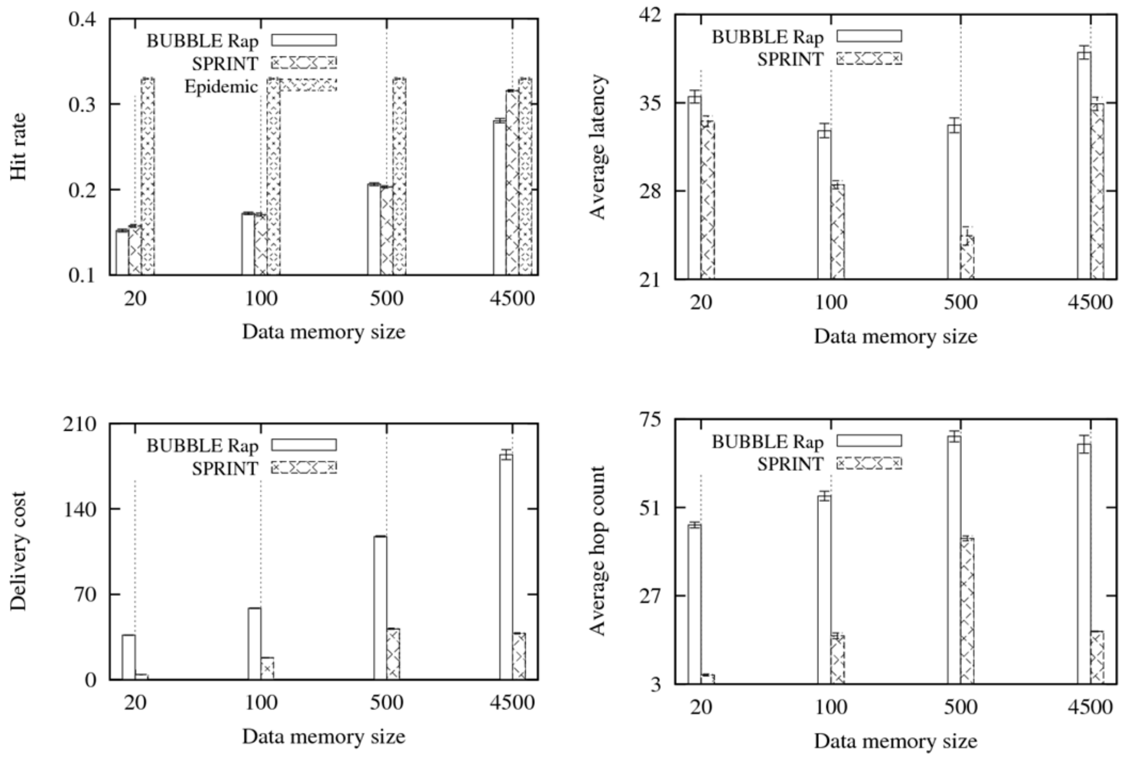


Figure 5. SPRINT results for Content.

ONSIDE

Information about the way the experiments were run for ONSIDE and more detailed results analysis can be found in (Ciobanu et al, 2014). Similar to SPRINT, in order to highlight the benefits of ONSIDE, we compare it to Epidemic. However, since the classic Epidemic algorithm is not entirely feasible in real life (given that it assumes an unlimited data memory), we also compare ONSIDE to a limited-memory version of Epidemic, that behaves exactly like the original implementation, except that, when the data memory is full and a new message should be downloaded, an existing message must be deleted from memory. We refer to this Epidemic version as Limited Epidemic. Aside from Epidemic, we also compare ONSIDE to a dissemination-modified version of ML-SOR (Socievole et al, 2013). We have chosen this algorithm since it is also interest-based and socially-aware like ONSIDE.

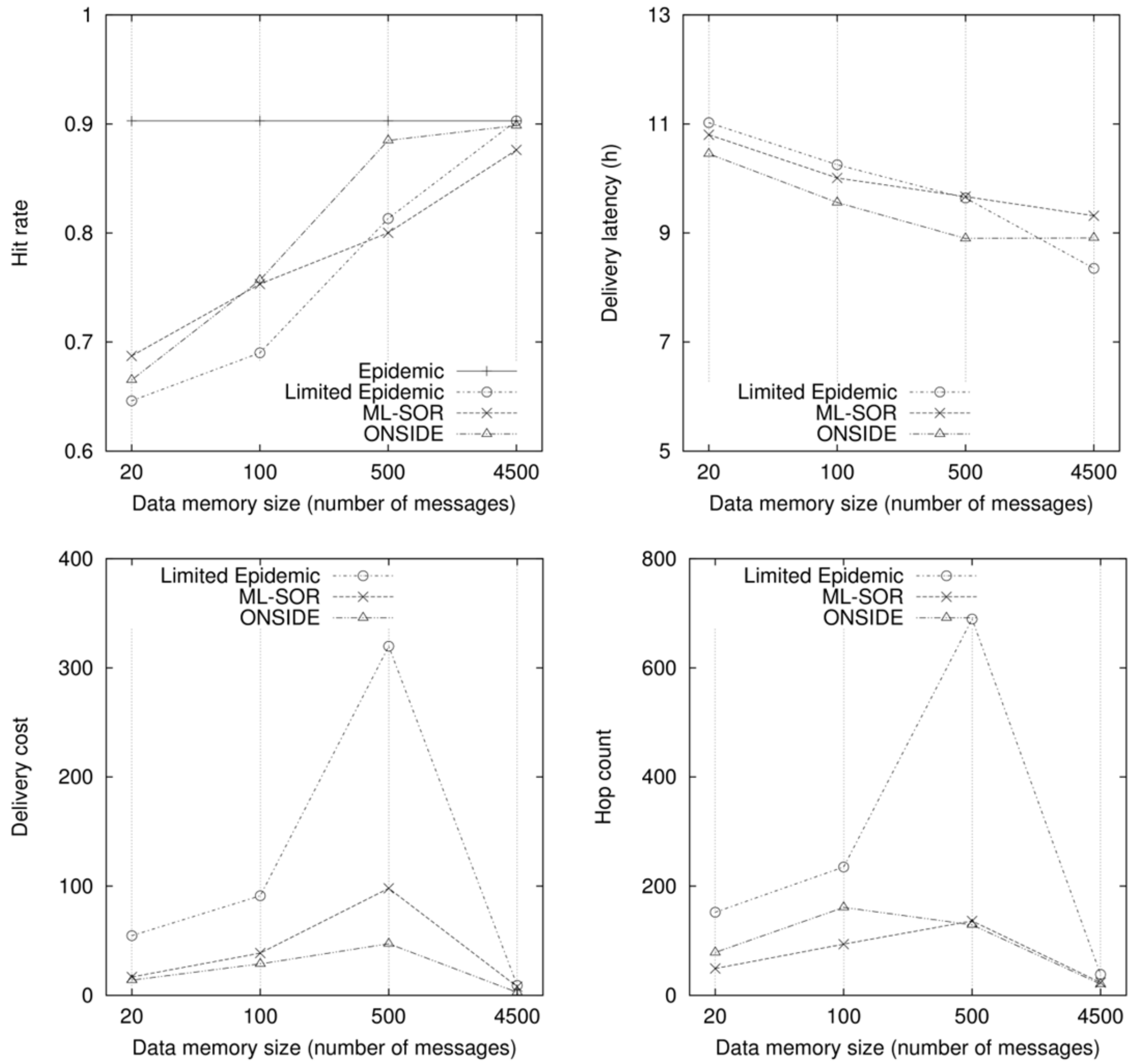
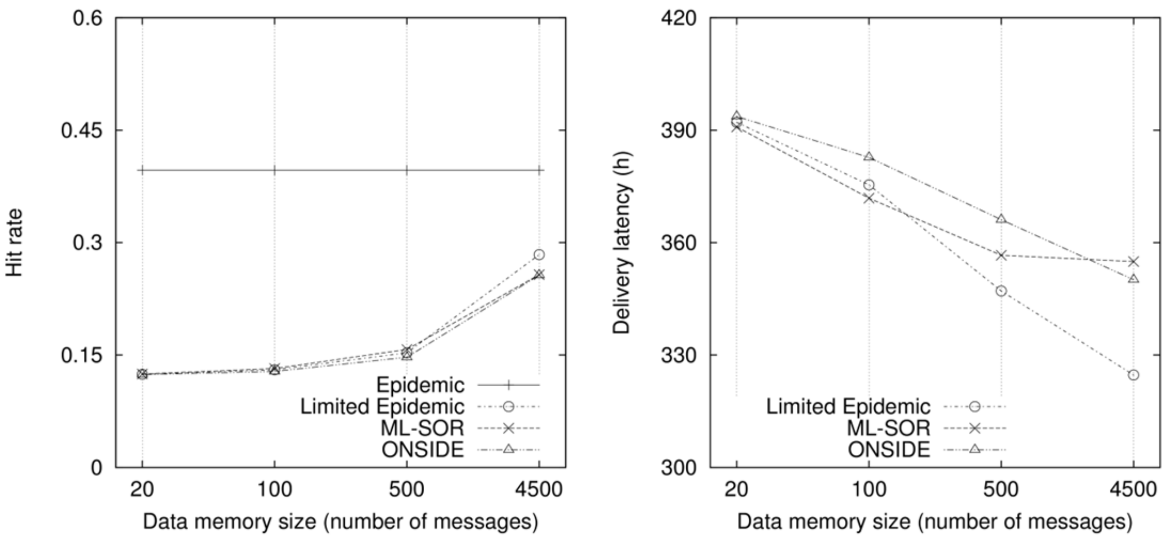


Figure 6. ONSIDE results for Sigcomm 2009.



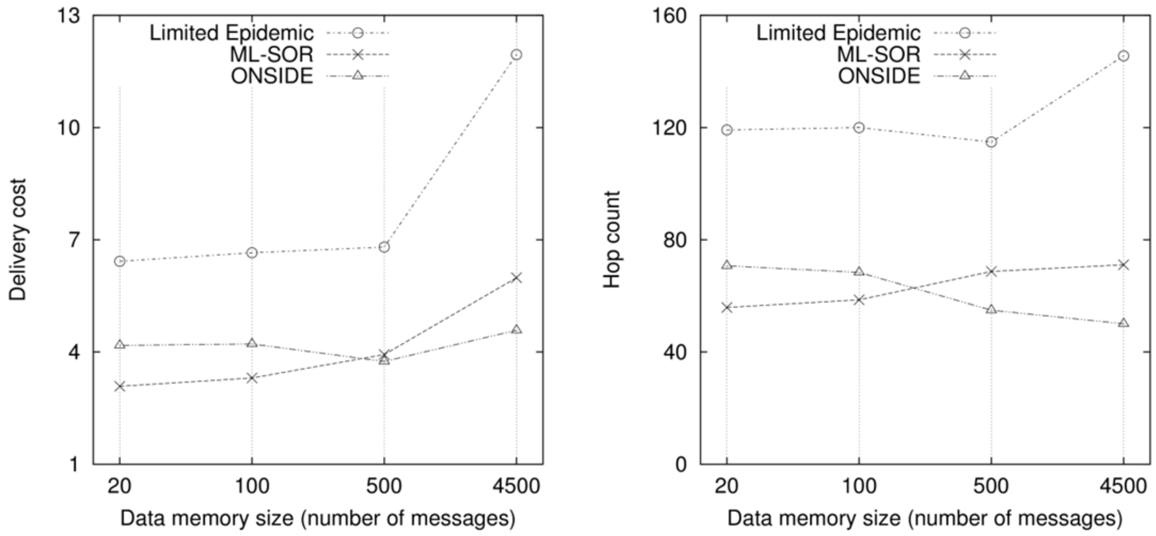


Figure 7. ONSIDE results for UPB 2012.

Figure 6 shows the results obtained by applying Epidemic, Limited Epidemic, ML-SOR and ONSIDE on the Sigcomm 2009 trace. It can be seen that ONSIDE generally performs better than both ML-SOR, as well as Limited Epidemic. For a data memory that can store 4500 messages, ONSIDE yields a hit rate that is very close to the maximum value obtained when running Epidemic and Limited Epidemic. Limited Epidemic is able to achieve maximum hit rate because the memory size is large enough to fit all the messages generated in the trace, since Sigcomm 2009's duration is only three days. The delivery latency chart shows similar results: ONSIDE is able to achieve a better delivery latency than ML-SOR regardless of the data memory size (with a maximum improvement of up to 1.7 hours), whereas Limited Epidemic only outperforms our algorithm when the data memory is large enough to store all the messages generated in the trace. However, the downside of Epidemic-based algorithms is evident from the delivery cost and hop count results, where it can be seen that the bandwidth used and the network and node congestion are really high. ONSIDE's delivery cost is lower than the ones obtained by Limited Epidemic and ML-SOR for all data memory sizes. Regarding hop count, ONSIDE again clearly outperforms Limited Epidemic for all data memory sizes, but it does achieve a higher hop count than ML-SOR for lower data memory sizes (like 20 and 100).

The UPB 2012 results are shown in Figure 7. Since the duration of the trace is much higher than Sigcomm 2009's, there are a lot more messages generated in the network, so the maximum hit rate is harder to achieve with a limited data memory. The ONSIDE algorithm performs similarly to both Limited Epidemic, as well as ML-SOR. Because this trace has a much longer duration that Sigcomm 2009 and the network is relatively sparse (with not many contacts), the delivery latency values are very high. Regardless of this, the values are similar for all three algorithms, with a slight edge for Limited Epidemic for higher data memory sizes. However, this comes with the cost of increased congestion and overhead, where Limited Epidemic performs much worse than ONSIDE and ML-SOR. Regarding delivery cost, ONSIDE performs the best out of all three algorithms for data memory sizes of 500 and 4500.

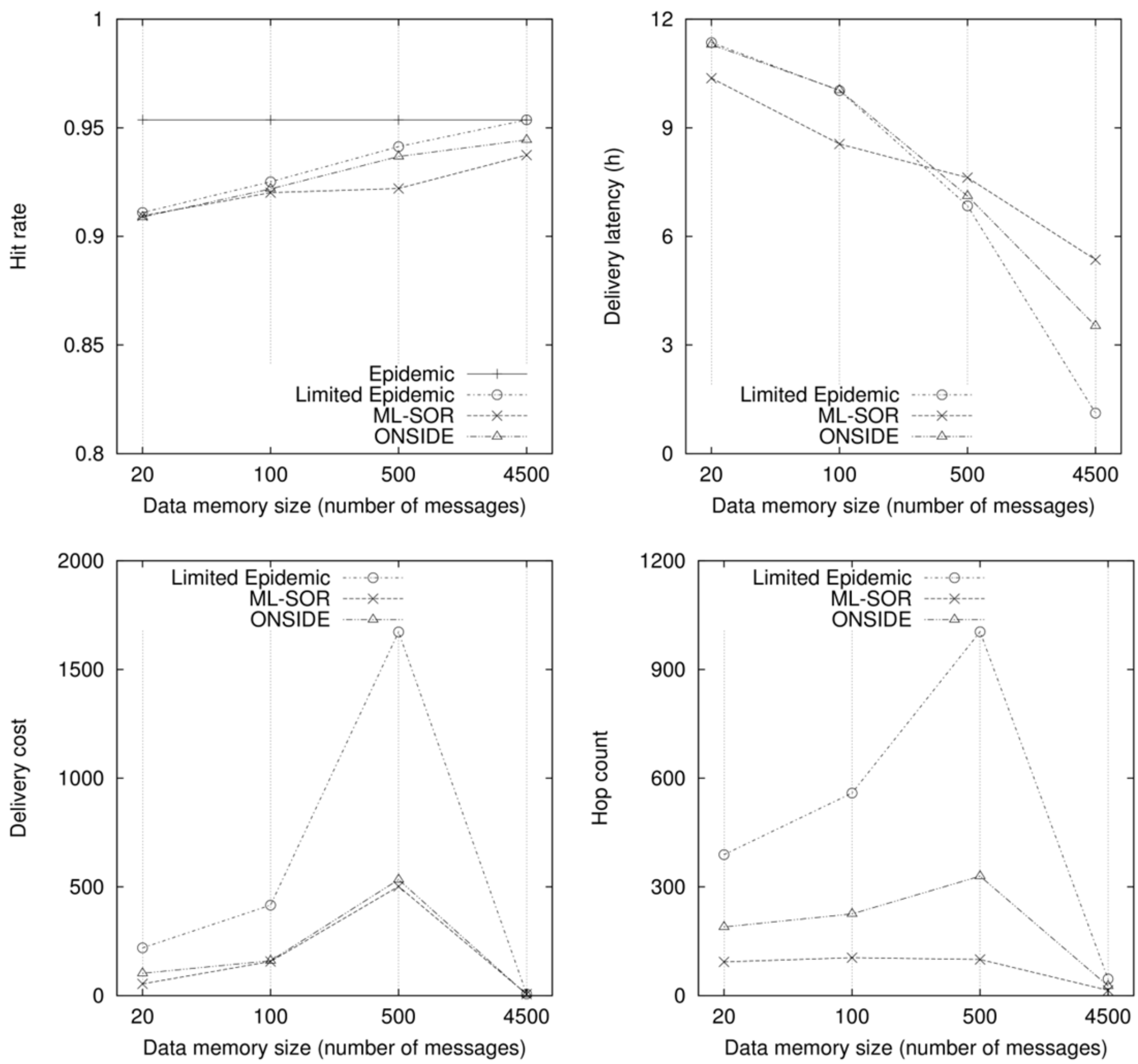


Figure 8. ONSIDE results for Infocom 2006.

Finally, the results for the Infocom 2006 trace are presented in Figure 8. Infocom 2006 has the disadvantage of not containing social information about the participating nodes, so the TSS component from ML-SOR will always be 0. Similarly, ONSIDE does not use the *InterestedFriends* component, since thr_f is set to 0. The results show that ONSIDE yields better hit rates than ML-SOR for all data memory sizes except 20, keeping close to the two Epidemic versions, especially when the data memory size is higher. Regarding delivery latency, ONSIDE fares better than ML-SOR for large memory sizes. Limited Epidemic has the best behavior in terms of latency, but it pays for it with a higher degree of congestion. The hop count obtained by Limited Epidemic is extremely large, about three times larger than the one ONSIDE yields. However, ML-SOR performs better in terms of hop count than both the other two solutions. The delivery cost is lower for ML-SOR and ONSIDE, with our solution faring much better when the data memory size is higher.

Therefore, the results show that, generally, both ONSIDE and ML-SOR barely affect the overall hit rate (with a slight advantage for ONSIDE), while decreasing the congestion and overhead. For most of the situations, ML-SOR seems to work better for lower data memory sizes, while ONSIDE fares well for nodes that are able to store more messages.

7. CONCLUSIONS

As of 2013, there were an estimated 44.4 million people with dementia worldwide. This number will increase to an estimated 75.6 million in 2030, and 135.5 million in 2050. Much of the increase will be in developing countries. Already 62% of people with dementia live in developing countries, but by 2050 this will rise to 71%. The fastest growth in the elderly population is taking place in China, India, and their South Asian and Western Pacific neighbors. Thus, a change in care for people with dementia is today necessary more than ever. Ambient Assisted Living (AAL) can provide an answer to this.

AALs are system designed to help, through the active use of Information and Communication Technologies (ICT), patients, caregivers and professionals alike. Such systems are designed to provide an ecosystem of medical sensors, computers, wireless networks and software applications for healthcare monitoring, and are designed to meet the personal healthcare challenges. Thus, it is no wonder that, presently, there is a huge demand for AAL systems, applications and devices for personal health monitoring and tele-health services.

Opportunistic communications use low-cost human wearable mobile nodes allowing the exchange of packets at a close range of a few to some tens of meters with limited or no infrastructure. Typically, cheap pocket devices which are IEEE 802.15.4-2006 compliant can be used and they can communicate at a 2-10 meters range, with local computational capabilities and local memory. Here we have proposed and described an autonomous patient monitoring support system based on opportunistic communications. The monitored patient wears non-intrusive sensors, and potentially computing devices and actuators, forming a body area network (BAN). This on-patient network can provide memory impairment support services for the patient, and is used to construct the personalized condition-monitoring patient model used to evaluate against a set of potential life-threatening events.

The system collects the measurements from the different sensors, on-body and also external sensors where available, aggregates the sensing data provided, and periodically transmits it toward a central station for further processing. When there is a direct Internet connection, this will be the preferred means to transmit the data. For indoor scenarios, it is more likely that a wired connection is available. However, things are different for outdoor scenarios. In the absence of an Internet connection, the patient might use ad-hoc networking alternatives to send the data to the Wireless Access Point located in his surroundings. Here, we employ the use of opportunistic networking techniques. These techniques will be used to also collect sensing data from the environment. For example, while the patient is walking by, he can connect to other mobile devices, carried by other people, and collect valuable sensing data. The nearby devices are also able to track the patient, so when they are placed together rescuers can use the tracking data to reconstruct the path followed by the dementia patient. Thus, the monitoring system uses opportunistic networking to connect to nearby devices for at least two causes: support for communication, and support for human tracking and sensor data sharing. Last but not least, when a critical event occurs, the Home Care System can use opportunistic dissemination to send an alert message to nearby people.

For outdoor living assistance in particular, this monitoring system may acquire additional context information, describing unforeseen situations. Since for outdoor living assistance the monitoring systems may never rely on a stable communication infrastructure, opportunistic networking techniques can provide valuable monitoring applications. To overcome the lack of connectivity, we propose applying a delay/disruption-tolerant network technique for tracking patients, making use of opportunistic, ad-hoc, and short-range wireless communications to disseminate data over the network in a store-carry-and-forward fashion.

To better illustrate what kind of solutions can work in such conditions, we have presented our dissemination and our routing algorithms that we have previously proposed, and that can be employed in the dementia patient monitoring system. SPRINT is an opportunistic routing algorithm that combines socially-aware routing, including both learned and offline social information about nodes, with a module capable to predict node behavior. Its purpose is to improve the hit rate when compared to other algorithms, while also keeping the overhead and delivery latency as low as possible. It is based on the knowledge that opportunistic nodes belonging to humans are inherently predictable, since the behavior of their owners is predictable (which is particularly true in case of dementia-suffering patients, where AAL systems are generally designed to support learning their predictable daily habits and to try to support them as best as possible through augmented memory-triggering support services). ONSIDE, our proposed solution, is a publish/subscribe-based algorithm that disseminates data in opportunistic networks based on nodes' interests, together with social information about the nodes in the ON. Its goal is to reduce the overhead of spreading the data, while not affecting the hit rate and the delivery latency. Such a dissemination opportunistic solution can be employed in the finding or tracking of patients in outdoor scenarios, or to support personalized memory-reminding services (such as sending data to interested volunteers in the park, who might help the patient and remind him to take his medication, or helping a patient suffering a memory loss get in contact with someone who can help).

We have also explained why we believe that our solutions can be successfully employed, and showed a set of results obtained when running our algorithms in simulations based on existing mobility traces. The results prove that both our opportunistic networking solutions can deliver good hit rates, while decreasing the congestion and overhead associated with data transmissions (an important aspect to consider when the system is used to concurrently monitor many different patients, each one generating different independent sensing messages).

8. FUTURE WORK AND CHALLENGES

In the near future, we aim to develop a prototype of the proposed patient monitoring system, to better illustrate how it can be applied to real-world conditions. This system will use opportunistic means of establishing connections with social participants in the environment whenever possible (for the benefits illustrated throughout this chapter). Of course, there are also several challenges we first need to consider in the near future.

Interoperability and integration of medical devices in healthcare systems processing citizens' vital signs are the most frequently addressed attributes in AAL systems and platforms. This is very important if the tele-monitoring system for dementia-suffering patients is to be integrated with various medical support systems already in use today (for example, with the medical systems available on hospital grounds). For monitoring of daily living activities, we could integrate with the Open Service Gateway Initiative (OSGi) platform. The Continua Alliance has also proposed its own reference architecture to construct an ecosystem of interoperable and connected medical devices for personal healthcare and well-being. We could integrate with this through their proposed Peripheral Area Network Interface (PAN-IF). Similarly, the Assisted Living Platform (ALIP) in the DALLAS (Delivering Assisted Living Lifestyles at Scale) program addresses interoperability as the major concern to achieve scalability in medical device communication. The Interoperability Toolkit (ITK) in DALLAS helps integrate systems based on standardizing technologies and interoperability specifications. More research in the ALIP reference architecture solves interoperability issues by using the DALLAS Interoperability Layer, which extends the ALIP platform with security features for user and component authentication. And there are several other standardization efforts that we aim to consider further.

The second important challenge relates to security, privacy and data protection for the monitored patient. Security and data protection are critical issues in healthcare systems, which exchange and store citizens' medical data. All monitored medical data is, of course, security-sensitive. Therefore, legislation provides guidelines to design authorization policies regarding access and usage of the medical data to avoid intentional misuse or accidental disclosure. Security is an important aspect to consider here, and we aim to further investigate the use of a Public Key Infrastructure-based data encryption and digital certificate infrastructure for ensuring confidentiality and integrity of the medical data. The solution might consist of collecting medical data from mobile/wearable sensors, and cataloging it depending on the level of privacy/protection needed. For example, the most critical data will be securely transmitted for access only to the caregivers and family members of the citizens. A photo of the patient (without references to the actual illness) might be disseminated to trustful users only when needed to support (track, add) the patient (as in the park scenario previously described).

Another challenge relates to the quality of the sensing data. Quality attributes have a greater impact on the usability of AAL systems. Sensors might read imprecise data, or the sensing data might be completely unavailable (e.g., the GPS sensing might be wrongly affected by the weather conditions, or it might not work at all indoors). In such cases, we aim to explore mechanisms to augment the sensing with external sensors (for example, indoors we will superimpose the sensing data from the BAN mote with the data collected from the sensors within the house premises, and for outdoor conditions, as described, the quality of the sensing data will be re-enforced against the set of sensing data obtained opportunistically whenever available for nearby mobile devices). This, of course, will need further research in the establishment of trust models for aggregating the sensing data.

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REFERENCES

Akyildiz, I. F., W. Su, Y. Sankarasubramaniam, & E. Cayirci (2002). Wireless sensor networks: a survey. *Computer networks*, 38(4), 393–422.

ALZ (2013), Alzheimer’s Association. *2013 Alzheimer Disease. Facts and Figures*. http://www.alz.org/downloads/facts figures 2013.pdf [Accessed March 2014].

Bigwood, G., D. Rehunathan, M. Bateman, T. Henderson, & S. Bhatti (2008). Exploiting self-reported social networks for routing in ubiquitous computing environments. In *Proceedings of the 2008 IEEE International Conference on Wireless & Mobile Computing, Networking & Communication* (pp. 484–489), Washington, DC, USA.

Bouwhuis, D.G., V.T. Taipale, H. Bouma, & J.L. Fozard (2007). Gerontechnology in perspective. *Gerontechnology*, 6(4), 190–216.

Braem, B., B. Latre, C. Blondia, I. Moerman, & P. Demeester (2008). Improving reliability in multi-hop body sensor networks. In *Proceedings of the 2nd International Conference on Sensor Technologies and Applications* (pp. 342–347), IEEE.

Caprani, N., J. Doyle, M. O'Grady, C. Gurrin, N. O'Connor, B. Caufield, & G. O'Hare (2012). Technology use in everyday life: Implications for designing for older users. In Proceedings of 6th Annual Irish Human Computer Interaction (HCI) Conference (iHCI 2012), NUI Galway, Ireland.

Chernbumroong, S., S. Cang, A. Atkins, & H. Yu (2013). Elderly activities recognition and classification for applications in assisted living. *Expert Systems with Applications*, 40(5), 1662–1674.

Ciobanu, R.-I., & C. Dobre (2012). Predicting encounters in opportunistic networks. In *Proceedings of the 1st ACM Workshop on High Performance Mobile Opportunistic Systems*, HP-MOSys '12 (pp. 9–14), Paphos, Cyprus, ACM.

Ciobanu, R.-I., C. Dobre, & V. Cristea (2012). Social aspects to support opportunistic networks in an academic environment. In *Proceedings of the 11th international conference on Ad-hoc, Mobile, and Wireless Networks*, ADHOC-NOW'12 (pp. 69–82), Berlin, Heidelberg, Springer-Verlag, Belgrad, Serbia.

Ciobanu, R.-I., C. Dobre, & V. Cristea (2013). SPRINT: Social prediction-based opportunistic routing. In *Proceedings of 2013 IEEE 14th International Symposium and Workshops on a World of Wireless, Mobile and Multimedia Networks* (WoWMoM 2013, pp. 1–7). IEEE, Madrid, Spain.

Ciobanu, R.-I., R.-C. Marin, C. Dobre, V. Cristea, & C. X. Mavromoustakis (2014). ONSIDE: Socially-aware and interest-based dissemination in opportunistic networks. In Proceedings of 6th *IEEE/IFIP International Workshop on Management of the Future Internet*, (ManFI 2014, pp. 1-6), Krakow, Poland.

Gieras, I. A. (2003). The proliferation of patient-worn wireless telemetry technologies within the us healthcare environment. In *Proceedings of 4th International IEEE Conference on Information Technology*, EMBS Special Topic on Applications in Biomedicine (pp. 295–298), IEEE, Birmingham, UK.

Hebert, L. E., J. Weuve, P. A. Scherr, & Denis A. Evans (2013). Alzheimer disease in the united states (2010–2050) estimated using the 2010 census. *Neurology*, 80(19), 1778–1783.

Hui, P., & J. Crowcroft (2007). Bubble Rap: forwarding in small world DTNs in ever decreasing circles. *Technical Report UCAM-CL-TR-684*, University of Cambridge Computer Laboratory.

Hui, P., J. Crowcroft, & E. Yoneki (2008). Bubble rap: Social-based forwarding in delay tolerant networks. In *Proceedings of the 9th ACM International Symposium on Mobile Ad Hoc Networking and Computing*, MobiHoc '08 (pp. 241–250), New York, NY, USA.

Hung, K., & Y.-T. Zhang (2003). Implementation of a wap-based telemedicine system for patient monitoring. *IEEE Transactions on Information Technology in Biomedicine*, 7(2), 101–107.

Khoor, S., J. Nieberl, K. Fugedi, & E. Kail (2001). Telemedicine ecg-telemetry with bluetooth technology. In *Proceedings of Computers in Cardiology* (pp. 585–588). IEEE.

Lee, R.-G., H.-S. Chen, C.-C. Lin, K.-C. Chang, & J.-H. Chen (2000). Home telecare system using cable television plants-an experimental field trial. *IEEE Transactions on Information Technology in Biomedicine*, 4(1), 37–44.

Lin, C.-C., P.-Y. Lin, P.-K. Lu, G.-Y. Hsieh, W.-L. Lee, & R.-G. Lee (2008). A healthcare integration system for disease assessment and safety monitoring of dementia patients. *IEEE Transactions on Information Technology in Biomedicine*, 12(5), 579–586.

Lindeberg, M., V. Goebel, & T. Plagemann (2010). Adaptive sized windows to improve real-time health monitoring: A case study on heart attack prediction. In *Proceedings of the International Conference on Multimedia Information Retrieval*, MIR '10 (pp. 459–468), New York, NY, USA.

Malan, D., T. Fulford-Jones, M. Welsh, & S. Moulton (2004). Codeblue: An ad hoc sensor network infrastructure for emergency medical care. In *Proceedings of International workshop on wearable and implantable body sensor networks*, vol. 5, Imperial College London, UK.

Marin, R.-C., C. Dobre, & F. Xhafa (2012). Exploring Predictability in Mobile Interaction. In *Proceedings of 2012 Third International Conference on Emerging Intelligent Data and Web Technologies* (EIDWT, pp. 133–139). Bucharest, Romania.

Mendoza, G.G., & B.Q. Tran (2002). In-home wireless monitoring of physiological data for heart failure patients. In *Proceedings of 24th Annual Conference and the Annual Fall Meeting of the Biomedical Engineering Society Engineering in medicine and biology*, (EMBS/BMES 2002, vol. 3, pp. 1849–1850), IEEE, NY, USA.

Migliardi, M., & M. Gaudina (2011). A context aware, mobile system providing memory support for ageing people. In *2011 Proceedings of the 34th International Convention* (MIPRO, pp. 535–540), Opatija, Croatia.

NINDS (2013), National Institute of Neurological Disorders and Stroke. *Dementia: hope through research*. Available http://www.ninds.nih.gov/disorders/dementias/detaildementia.htm [Accessed March 2014].

Pattichis, C.S., E. Kyriacou, S. Voskarides, M.S. Pattichis, R. Istepanian, & C.N. Schizas (2002). Wireless telemedicine systems: an overview. *IEEE Antennas and Propagation Magazine*, 44(2), 143–153.

Pietilainen, A.-K., E. Oliver, J. LeBrun, G. Varghese, & C. Diot (2009). MobiClique: middleware for mobile social networking. In *Proceedings of the 2nd ACM workshop on Online social networks*, (WOSN '09, pp. 49–54), New York, NY, USA.

Pollard, J.K., S. Rohman, & M.E. Fry (2001). A web-based mobile medical monitoring system. In *Proceedings of International Workshop on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications* (pp. 32–35). IEEE, Foros, Ukraine.

SCIE (2012), Social Care Institute for Excellence. *Using ict in activities for people with dementia: A short guide for social care providers*, Available online http://www.scie.org.uk/publications/ictfordementia/ [Accessed March 2014].

Scott, J., R. Gass, J. Crowcroft, P. Hui, C. Diot, & A. Chaintreau (2006). *CRAWDAD data set* cambridge/haggle (v. 2006-01-31). Available http://crawdad.org/cambridge/haggle/ [Accessed March 2014].

Sehgal, S., M. Iqbal, & J. Kamruzzaman (2007). Ambient cardiac expert: a cardiac patient monitoring system using genetic and clinical a cardiac patient monitoring system using genetic and clinical knowledge fusion. In *Proceedings of 6th IEEE/ACIS International Conference on Computer and Information Science* (ICIS 2007, pp. 496–501). IEEE, Los Alamitos, USA.

Søberg, J., V. Goebel, & T. Plagemann (2010). Detection of spatial events in commonsens. In *Proceedings of the 2Nd ACM International Workshop on Events in Multimedia* (EiMM ’10, pp. 53–58), New York, NY, USA, ACM.

Socievole, A., E. Yoneki, F. De Rango, & J. Crowcroft (2013). Opportunistic message routing using multi-layer social networks. In *Proceedings of the 2Nd ACM Workshop on High Performance Mobile Opportunistic Systems* (HP-MOSys ’13, pp. 39–46), Barcelona, Spain, 2013. ACM.

Vahdat, A., & D. Becker (2006). Epidemic routing for partially connected ad hoc networks. *Technical Report CS-200006* (pp. 18), Duke University.

Varshney, U. (2007), Pervasive healthcare and wireless health monitoring. *Mobile Networks and Applications*, 12(2-3), 113–127.

Varshney, U. (2008), A framework for supporting emergency messages in wireless patient monitoring. *Decision Support Systems*, 45(4), 981–996.

Key Terms and Definitions:

Ambient Assisted Living is predominately an European term, that describes technologies aiming to enhance the quality of life of older people through the use of Information and Communication Technologies (ICT). The term ambient relates to the use of non-invasive sensors, such as motion detectors, which help understand how people live their lives and hence detect when things change possibly showing a negative decline. This area may also be referred to by many other names such as; Aging in place, Ageing in place, Independent living, telemedicine, tele-monitoring or tele-surveillance.

Opportunistic mobile networks consist of human-carried mobile devices that communicate with each other in a store-carry-and-forward fashion, without any infrastructure. Compared to the classical networks, they present distinct challenges. In opportunistic networks, disconnections and highly variable delays caused by human mobility are the norm rather than an exception. The solution consists of dynamically building routes, as each node acts according to the store-carry-and-forward paradigm. Thus, contacts between nodes are viewed as opportunities to move data closer to the destination. Such networks are therefore formed between nodes spread across the environment, without any knowledge of a network topology. The routes between nodes are dynamically created, and nodes can be opportunistically used as a next hop for bringing each message closer to the destination. Nodes may store a message, carry it around, and forward it when they encounter the destination or a node that is more likely to reach the destination.

Dementia is not typically a specific disease, but rather is a term that describes a group of symptoms affecting thinking and social abilities severely enough to interfere with daily functioning. Many causes of dementia symptoms exist. Alzheimer's disease is the most common cause of a progressive dementia. Memory loss generally occurs in dementia. However, memory loss alone doesn't mean you have dementia. Dementia indicates problems with at least two brain functions, such as memory loss and impaired judgment or language, and the inability to perform some daily activities such as paying bills or becoming lost driving.

SPRINT (Social PRedIction-based routing in opportunistic NeTworks) (Ciobanu et al, 2013) is an opportunistic routing algorithm that combines socially-aware routing, including both learned and offline social information about nodes, with a module capable to predict node behavior.

ONSIDE (OpportuNistic Socially-aware and Interest-based DissEmination) (Ciobanu et al, 2014) is a publish/subscribe-based algorithm that disseminates data in opportunistic networks based on nodes' interests, together with social information about the nodes in the ON. Its goal is to reduce the overhead of spreading the data, while not affecting the hit rate and the delivery latency.

The **hit rate**, computed as the ratio between successfully delivered and total messages, is a metric that suggests the efficiency of a routing algorithm, and ideally it would be 100%. It shows the fraction of requests that can be served by a routing algorithm.

The **delivery cost**, represents by the ratio between the total number of exchanged messages during the course of the experiment and the number of generated messages. The metric should be as low as possible and it shows the congestion of the network.

The **latency** show the time (in seconds) passed between generating a message and delivering it to the destination. In an opportunistic network, which is a type of delay tolerant network (DTN), delivery latency should be improved when possible.

The **hop count** metric describes the number of nodes that carried a message until it reached the destination on the shortest path.

INDEX TERMS

LIST OF ACRONYMS

AAL - Ambient Assisted Living
ACE - Ambient Cardiac Expert
ALIP - Assisted Living Platform
BAN - Body Area Network
CEP - Complex Event Processing
DALLAS - Delivering Assisted Living Lifestyles at Scale
EKG - Electrocardiogram
GIS - Geographic Information System
GPRS - General Packet Radio Service
GPS - Global Positioning System
ICT - Information and Communication Technology
ITK - Interoperability Toolkit
LTE - Long-Term Evolution
LoI - Location of Interest
ON - Opportunistic Network
ONSIDE - OpportuNistic Socially-aware and Interest-based DissEmination
OSGi - Open Service Gateway initiative
PAN-IF - Peripheral Area Network Interface
RFID - Radio Frequency Identification
SPRINT - Social PRedIction-based routing in opportunistic NeTworks
TTS - Tame Transformation Signatures
WSN - Wireless Sensor Network