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Contents

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List of Definitions

Term	Meaning
DTN	Delay Tolerant Network (DTN) is an emerging technology that supports interoperability of other networks by accommodating long disruptions and delays between and within those networks. DTN operates in a store-and-forward fashion where intermediate nodes can temporary keep the messages and opportunistically forward them to the next hop. This inherently deals with temporary disruptions and allows connecting nodes that would be disconnected in space at any point in time by exploiting time-space paths.
ICN	Information-Centric Network (ICN) has emerged as a promising solution for the future Internet's architecture that aims to provide better support for efficient information delivery. ICN approach uniquely identifies information by name at the network layer, deploys in-network caching architecture (store information at the network node) and supports multicast mechanisms. These key mechanisms facilitate the efficient and timely information (contents and services) delivery to the end-users.
Content	Content refers to a piece of digital information that is disseminated and consumed by end-user equipment.
Node	A wireless or wired capable device.
User	An entity (individual or collective) that is both a consumer and a relay of user services.
User Interest	A parameter capable of providing a measure (cost) of the “attention” of a user towards a specific (piece of) information in a specific time instant. Particularly, users can cooperate and share their personal and individual interests that enable the social interactions and data sharing across multiple users.
User Requirement	User requirement corresponds to the specifications that users expect from the application.
Upstream	Upstream traffic refers to outgoing data such as short message, photo or uploading video clips that are sent from user equipment.
Downstream	Downstream traffic refers to data is obtained by use equipment from network. This includes downloading files, web page, receiving messages, etc.
Gateway	Gateway typically means an equipment installed at the edge of a network. It connects the local network to larger network or Internet. In addition, gateway also has a capability to store services and contents in its cache to subsequently provide local access communication.

UMOBILE System	UMOBILE System refers to an open system that provides communication access to users through wired or wireless connectivity. This system exploits the benefit of local communication to minimize upstream and downstream traffic. The services or contents can be exchanged and stored in several devices such as gateways; user equipments; customer premises equipments such as Wi-Fi Access Points in order to efficiently delivery the desired contents or services to end-users.
UMOBILE Architecture	A mobile-centric service-oriented architecture that efficiently delivers contents and services to the end-users. The UMOBILE architecture integrates the principles of Delay Tolerant Networks (DTN) and Information-Centric Networks (ICN).
User-equipment	User-equipment (UE) corresponds to a generic user terminal (for example smart phone or notebook). In terms of UE and for operating systems we consider mainly smartphones equipped with Android; notebooks with UNIX, Windows, Mac OS.
Application	Computer software design to perform a single or several specific tasks, e.g. a calendar and map services. In UMOBILE, context-aware applications are considered.
Service	Service refers to a computational operation or application running on the network which can fulfil an end-user's request. The services can be hosted and computed in some specific nodes such servers or gateways. Specifically, service is normally provided for remuneration, at a distance, by electronic means and at the individual request of a recipient of services. For the purposes of this definition;*"at a distance"* means that the service is provided without the parties being simultaneously present; *"by electronic means"* means that the service is sent initially and received at its destination by means of electronic equipment for the processing (including digital compression) and storage of data, and entirely transmitted, conveyed and received by wire, by radio, by optical means or by other electromagnetic means; *"at the individual request of a recipient of services"* means that the service is provided through the transmission of data on individual request. Refer to D2.2 for further details. Services, in this work can also be placed in end-users devices and provide information to other users using D2D communications.
NDN	Named Data Networking
NREP	Name-based REPlication Priorities
D2D	Device-to-Device communications

Executive Summary

This deliverable (D4.3) summarizes the work developed in WP4 (Services Enablement, month 6 to month 30), task 4.3 (Name-based replication priorities, month 6 to month 24).

The main objective of WP4 is to enhance UMOBILE architecture in terms of QoS and QoE and enable solutions that take advantage of the unique features of the developed architecture. This WP will use the architecture developed during WP3 to provide a set of services. Hence, the outcome of WP4 is the enablement of services that support the key characteristics of the developed platform, such as the provision of multiple QoS levels and the collection, processing and dissemination of different types of data.

The main goal of task 4.3 was to develop mechanisms that assist the UMOBILE architecture in supporting a mobile name-based replication system, where message replication is limited by time and space, that is, within a certain geographic area and with specific life expectancy. As starting point in the task, replication optimization was based on prioritization rules expected to be integrated within the information message’s name to favor spreading of the most important messages. This prioritization rules will include as well some social parameters in order to select first the best node to replicate the information.

The focus was on cases where Internet access is intermittent (mobile infrastructure may not always be accessible) or missing and therefore messages would have to be stored, carried, as well as forwarded via mobile nodes.

Deliverables related with this deliverable are deliverables D2.1 and D2.2, which describe the requirements from the end-user (D2.1) and the system (D2.2) perspective; deliverables D3.1 and D3.3 which describe the UMOBILE architecture.

The deliverable is organized as follows: Section 1. gives a brief introduction on the topic of name-based replication, motivation and goals of this task. Section 2 presents background work on data and content replication, focusing on social-aware approaches and describing in detail UMOBILE NREP. Section 3 concerns device-to-device communication and information-centric aspects, focusing on direct communication between end-user devices based on Wi-Fi direct, as this is the technology considered in UMOBILE. Section 4 presents the NREP adaptation in UMOBILE. Section 5 provides the validation carried out via discrete event simulations. Section 6 concludes this deliverable.

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1 Introduction

The UMOBILE architecture sustains the efficient delivery of content/services to end-users in the context of challenged networks, where often there is intermittent connectivity. To achieve this, UMOBILE considers the decoupling of content/services from their origin location and goes beyond a host-centric paradigm to a new paradigm: information-centric and opportunistic networking principles are combined to i) improve service delivery (e.g., take advantage of traffic locality); ii) improve the social routine of the end-user via technology (e.g., assist in the development of services that take into consideration crowd analysis parameters, or interests shared among familiar strangers).

In UMOBILE, the approach followed pushes network services (e.g., mobility management, intermittent connectivity support) and user services (e.g., pervasive content management) as close as possible to the end-users. With this approach, UMOBILE expects to improve service availability and delivery in the different scenarios described in deliverable D2.2.

In the context of the scenarios supported by UMOBILE, data transfer is performed via mobile, end-user devices. Users carrying such devices will not always be aware of the origin of the content/service. Likewise, the sources of data and services may not even know the destination. Hence, the principles of carry-and-forward are not applicable in this case, being replaced by the data-centric approach of store-and-forward. End-to-end paths may not be always available; the topology becomes highly variable.

Hence, in UMOBILE, it is relevant to consider forwarding strategies as well as replication strategies to disseminate content that can reach interested users, and this should be performed at a network level, as applications may not always be able to identify users interested in the data.

A second challenge in the context of UMOBILE concerns the fact that UMOBILE deals with two types of networking environments: one where there is an infrastructure, and one where communication is opportunistic, based on constrained mobile devices. Hence, content and data dissemination need to be made aware of resource consumption to be as efficient as possible.

A third aspect that is relevant in the aforementioned context and that we have considered when devising the proposed replication scheme concerns the fact that the majority of devices considered in the UMOBILE scenarios are mobile end-user devices. In related work, social behavior derived from network mining (e.g., inter-contact times; number of nodes around; similar interest in context) has been proven relevant in the context of opportunistic networking [1][2], as such behavior is an indicator not only of

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the mobility pattern of users, as well as relevant in the context of similarity correlation over time and space [26].

To assist in overcoming the three mentioned aspects we have devised a name-based replication priority mechanism which considers indicators of social routine behavior of users (e.g. density of clusters around a device; battery status of devices) collected via the UMOBILE Contextual Manager Module, to assist in a more efficient data dissemination. The proposed mechanism is derived from the *Name-based Replication Protocol (NREP)* solution [4]. In UMOBILE we have adapted NREP to the requirements of our system, being the value –add to background work **i) the integration of social-awareness to perform prioritization; ii) validation carried out via simulations for the emergency scenario of UMOBILE.**

The remainder document is organized as follows. Section 2 presents background work on data and content replication, focusing on social-aware approaches and describing in detail UMOBILE NREP. Section 3 concerns device-to-device communication and information-centric aspects, focusing on D2D based on Wi-Fi direct, as this is the technology considered in UMOBILE. Section 4 presents the NREP adaptation in UMOBILE. Section 5 provides the validation carried out via discrete event simulations. Section 6 concludes this deliverable.

2 Contributions Towards Related Work

2.1 Social-Aware Data Replication Approaches

In what concerns data dissemination, social awareness has been in the rise in particular when considering the capability of exploiting the mobility of personal devices to reduce the need for data muling, as well as to exploit traffic locality as a way to improve service/content delivery. Of relevancy to our work are data dissemination strategies in challenged environments, where there is not always a path between source(s) and destination(s), as well as in opportunistic networks. In this type of environment, nodes are not necessarily aware of the caching possibilities, nor of the origin of content.

Several authors have developed social-aware opportunistic mechanisms for data dissemination in the context of opportunistic routing [1][2], while there is also a relevant area of work in regards to opportunistic data exchange. For instance, in the PodNet architecture [6] users advertise the data objects that they have interest in. When two nodes meet, they decide whether to exchange data based on the information gathered in terms of categories of interests. Contentplace [4] builds upon this notion, adding the novelty of exchanging short summaries for the data objects they are carrying, thus contributing a decentralized dissemination solution.

The solutions mentioned are based on utility-based caching strategies. Other relevant strategies in the UMOBILE context are incentive-based strategies [7]; user-centric strategies [8]; cognitive approaches [8].

The approaches mentioned address performance in terms of replica reduction by applying decision methodologies from a local perspective (when two nodes meet). While some already consider summaries of content, most simply consider the opportunities of contact.

Our approach focuses on the decision-making process based on content naming, as occurs in ICN. ICN, with its focus on content-centricity-based forwarding, allows for nodes (i.e., routers, in case of the fixed Internet infrastructure, or intermediate node, in case of opportunistic mobile networks) to make decisions based on content naming policies. It is our belief that this approach is required when considering future wireless networks, as described in the UMOBILE use-cases. Furthermore, based on emergency scenarios, it is also essential to consider content naming prioritization strategies, where replication is optimised by prioritisation rules, integrated within the content message's name to benefit the dissemination of the most "important" messages, where relevancy can be either signaled statically, or provided via dynamic parameters (contextualization). Hence, NREP follows a prioritization-based utility approach.

2.2 NREP: Name-based Replication Protocol

NREP attempts to leverage the benefits of ICN in the aftermaths of a disaster, where ad hoc DTN communication becomes essential in order to deal with fragmented networks and the increase in traffic demand. Because of the need of a name-based forwarding/replication scheme, in NREP intermediate nodes use a name associated with each message to make decisions such as whether to replicate and if so, according to what priority, or otherwise, store(-and-carry) and for how long storage should be allocated. Moreover, other parameters such as priority, time-to-live and geographical constraints in the name or as attributes of the name are considered in order to help increase the efficiency of intermediate nodes to make decisions on storage and replication.

NREP borrows from ICN principles of using content names as the primary means for routing. However, unlike conventional ICN that is primarily designed to support name-based routing in an infrastructure-based environment, NREP is designed to operate in an infrastructureless environment and focuses on name-based replication, rather than routing. The design challenges of NREP presented in previous work [1] were: (i) to identify what are the parameters that help differentiate between the various messages; (ii) to choose which of the parameters that influence message replication to include in the name and which to include as attributes; and (iii) to identify and understand the resulting trade-offs.

In [1] the parameters used for differentiation were:

- Priority: based on the predefined hierarchical name space for emergency services. For instance, the hierarchical name-prefix could look like: Emergency/SOS or Emergency/Fire where the former could be considered to have higher global priority than the latter
- Space: the geographical reach within which the data is considered valid.
- Temporal validity: lifetime of the content.

However, initial NREP approach does not take into consideration other parameters that can also be vital in order to replicate emergency messages in the best way to reach the required users. For example, it does not take into account the energy of devices, which might be a scarce resource, network conditions or social strength to destination.

Since NREP is aimed to be developed over the UMOBILE platform and using Wi-Fi Direct communications for Android devices, when we need to broadcast a message within a certain area, it is necessary to first establish a Wi-Fi Direct group and broadcast the emergency message in this group, being this group formed by 2 peers or more. This connection period takes some time and adds an important latency to the communications, being up to 10 seconds in certain situations [9]. This latency cannot be omitted in mobile scenarios where contacts are short in duration time, since during that time the number of contacts around can change, losing contact with some of the users that were around. We need to prioritise those contacts with users that will have more affinity to the recipient of the message than others users.

To this end, we believe that we should take into account not only priorities between different content, but also we should have to prioritise Wi-Fi Direct group establishments between those peers that are more suitable for their mobility history. This task considers NREP as basis as to include social encounters in the connectivity manager aimed at prioritise connections with the best users to send emergency information.

Then, the task shall integrate other measures of affinity and develop NREP extensions for priorities, derived from contextual data, provided by the UMOBILE context manager module. In the following section, we give more details of which parameters are considered and the operation of the new name-based replication scheme. We also describe the design of the scheme into the UMOBILE architecture and which modules are required in order to implement the NREP scheme.

3 Direct Device Communication and Information-Centric Connectivity

Powerful end-user devices can act as data sources and take advantage of local connectivity (through Wi-Fi Direct, LTE Direct, Bluetooth, Google Nearby[1]). Although these technologies have been around for quite a while (the first Bluetooth distribution came out more than a decade[2]) there have been surprisingly few (mainly gaming and chat applications, e.g., FireChat) applications that exploit such connectivity in a user-transparent way. That said, links between devices (with speeds that can reach up to 250Mbps for Wi-Fi Direct and 25Mbps for Bluetooth 4.0) remain largely unused.

More recently, we have observed the emergence of similar paradigms in cellular networks. LTE-direct is a feature of LTE still under standardization that allows end-user devices to communicate directly (downlink) in a range of up to 500 meters. Based on FlashLinq by Qualcomm, LTE Direct goes beyond Wi-Fi direct in the capability to share access in terms of range as well as in terms of neighbor discovery density. It broadcasts sub-frames to discover neighbors (other devices that broadcast LTE direct beacons). Then, it relies on an exchange of public/private "expressions", i.e. strings that the devices can broadcast (during a service registration phase) to advertise services and/or develop and exchange affinities.

In this project, we set off to build an *information-aware and application-centric* device to device (D2D) opportunistic connectivity framework and realise a distributed and ubiquitous content distribution platform. In the current/traditional *client-server* model, content is pulled from the Internet upon the user's request. Instead, UMOBILE attempts to distribute and make content available to users without having Internet connectivity or before the user are able to check for updates. Although someone might argue that pre-fetching vast amounts of data to mobile devices will result in waste of bandwidth resources, NREP utilises local D2D connectivity to complete content transfers. That said, it does not consume network bandwidth resources, while the impact on the device's energy consumption is negligible, as we show through our proof-of-concept testbed measurements in Section 5.

We assume that nodes use the Wi-Fi Direct specification to exchange application content updates. Wi-Fi CERTIFIED Wi-Fi Direct® is a certification mark for devices supporting a technology that enables Wi-Fi devices to connect directly, making it simple and convenient to do things like print, share, sync and display, i.e., without Internet access. Hence, smartphone devices with the appropriate hardware (e.g., any Wi-Fi device using IEEE 802.11 drivers[3]) can connect directly to each other. For example,

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[1] https://developers.google.com/nearby/

[2] https://www.bluetooth.com/about-us/our-history

[3] https://wireless.wiki.kernel.org/en/developers/documentation/nl80211

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Android phones use the Wi-Fi P2P framework that complies with the Wi-Fi Direct certification program. Wi-Fi Direct devices need to negotiate their role in the communication [27]: in terms of networking architecture, one of them plays the role of a controller (AP), called *Group Owner* (GO) or *P2P Group Owner*; the remainder act as stations and are named *P2P Clients*. Hence, Wi-Fi Direct recurs to MAC virtualization in order to allow devices to perform direct device-to-device communication while at the same time being connected e.g. via wireless to its regular infrastructure access. The GO and client roles are dynamic and negotiated at the time of setup. For instance, all devices in the beginning can be GO of different services, e.g., UMOBILE. Then, devices go over a period of discovery (*Peer Discovery*); role negotiation *(P2P client and P2P GO*) and group establishment. Once a group is established, other P2P clients can joint, following the usual Wi-Fi procedures. Furthermore, regular Wi-Fi stations can communicate with the P2P GO as long as they support the required security mechanisms (by default, WPA2PSK). Therefore, legacy devices simply see the P2P GO as a regular AP. The P2P Go operates as a regular AP in infrastructure mode. It announces itself via management frames (MAC beacons) that carry additional P2P information (*P2P Information Element, P2P IE*). Legacy devices simply ignore such information, while devices involved in the P2P group can interpret it. Furthermore, the Wi-Fi Direct specification requires that the P2P GO provides also DHCP server support to then provide P2P clients in the respective group with IP addresses. Only the P2P GO is allowed to forward data to other devices (in an external data). Finally, Wi-Fi Direct does not allow transferring the role of P2P GO within a P2P group. Hence, if the device holding the P2P GO role goes away or down, the group is torn down. A full specification of Wi-Fi Direct architecture can be found in [27]. To assist in a better understanding of NREP in the context of UMOBILE, let us explain briefly how 2 devices establish a UMOBILE P2P group, and where NREP fits:

- **Neighbor Discovery/Group formation Phase.** Group formation involves 2 phases: I) finding a P2P GO; ii) provisioning of the P2P group owner. Finding a P2P GO implies negotiating the role or simply accept data sent about an owner – this is performed via the application. Assuming an application recurs to negotiation, then Wi-Fi directs usually start by performing regular Wi-Fi scanning (passive or active), which allows them to discover existent P2P groups/Wi-Fi networks. After this, devices execute a new Discovery algorithm, where a P2P device selects one of the Wi-Fi Direct "Social channels" (channels 1,6, 11 in the 2.4 GHz band) as its *Listen channel*. Then the device alternates between 2 states: search (active scanning, sending Probe Requests in all social channels); listen (respond with Probe Responses). Assuming an application considers a Persistent Group definition, then devices use a flag in the P2P Capabilities attribute in Beacon frames, then each devices stores network

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credentials and then assigned P2P GO and client roles (in the next re-instatiations of the P2P Group).

- **Service/Application Discovery:** Wi-Fi Direct supports service discovery **at the link layer**. Hence, prior to the establishment of groups, devices can exchange information (e.g. queries, meta-data) about their available applications. This is an optional step, but highly relevant in the context of opportunistic data dissemination. Wi-Fi Direct devices can advertise services/applications by attaching information at the management frames (i.e., beacons, probe requests and responses) through the usage of the *Generic Advertisement Protocol (GAS)* specified in 802.11u [11]. NREP, as well as all UMOBILE opportunistic applications, exploit the management frames of GAS to exchange information related to the device's applications. Through management frames, NREP source nodes share the applications they distribute content for, as well as the latest update they have. GAS management frames can be used to share information regarding *application name*, *transport protocol*, *port number, etc*. This way, users can share necessary application information before forming groups.
- **Group Formation**: Once two devices have found each other and are willing to share information, they start the group formation following one of the three different ways:
    - *Standard mode*: The basic GO Negotiation phase is implemented using a three-way handshake, sending the GO negotiation Request, Response and Confirmation messages. The two devices agree on which device will act as GO and on the channel where the group will operate. For the prototype results we present later in Section 5, we use this Standard mode, since it is the default mode for the Android implementation.
    - *Autonomous mode*: A device may autonomously create a group, where it immediately becomes the GO. It starts sending beacons at a chosen channel, without initiating any negotiation with any other device. Other devices can discover and participate in the established group using traditional scanning mechanisms. In this mode no GO Negotiation phase is required.
    - *Persistent mode*: Devices can declare a group as persistent, by using a flag in the capabilities attribute present in beacon frames, probe responses and GO negotiation frames. In that way, the devices forming the group store network credentials and the assigned GO and client roles for subsequent re-instantiations of the group.

Note that devices implementing Wi-Fi Direct may support concurrent operation through multiple groups simultaneously.

As mentioned in [12] the integration of an effective incentive mechanism in a user-operated replication mechanism is a challenging problem. Incentives should be provided to relay nodes in order for a user-operated opportunistic communications to succeed. In an attempt to encourage source nodes to participate, a "*couponing*" scheme similar to the one presented in [13] can be exploited. According to [13], compensation is based on the actual volume of the delivered/offloaded content. This approach is highly suitable for the case the work presented here as different nodes have different mobility patterns (e.g., office worker vs. bus driver) and will therefore, deliver different amounts of content. In case of different scenarios of mutual interest, such as a football match or a music concert, incentives are built on the grounds of camaraderie among fans of the same team/artist [14].

In order to ensure data integrity (i.e., content is what it claims it is and has not been modified by intermediate users), NREP integrates digital signatures (e.g., HMAC) based on Public Key Infrastructure (PKI). This setup prerequisite that the digital certificates used by the application provider do not expire while the users are disconnected. This way, users can easily authenticate the content they are receiving. Other security vulnerabilities, such as, eavesdropping, privacy violation, or denial-of-service (DoS) attacks, are out of the scope of this paper. However, related literature provides ways to deal with such issues in D2D communications (e.g.,[15]).

4 NREP in UMOBILE

NREP has first been devised to support the emergency scenario, as this scenario embodies several relevant requirements. For instance, it integrates crowds with high density; topology is highly variable; devices hold heterogeneous resources, and the origin and destination of content are not necessarily known.

In such scenarios, adequate replication strategies are required. These services will be supported by using replication, optimised by prioritisation rules, integrated within the information message's name to favor spreading of the most important messages, related to the emergency services. For example, in the case of an emergency in a disaster area, we consider messages from first responders as more important than messages between friends. We focus on cases where the mobile network infrastructure is not available and therefore messages have to be stored, carried and forwarded by mobile devices. In this task, we attempt to leverage the benefits of ICN in the aftermaths of a disaster, where opportunistic delay-tolerant communication becomes essential in order to deal with fragmented networks and the increase in traffic demand.

As explained in Section 2.2., the previous NREP version devised by UCL relies on the use of content names as the primary means for forwarding. However, unlike conventional ICN that is primarily designed to support name-based routing in an infrastructure-based environment, NREP is designed to operate in a service-centric, opportunistic environment and focuses on name-based replication, rather than on routing.

In UMOBILE, the solution considered relies on name-based forwarding/replication scheme, wherein intermediate nodes use a name associated with each message to make decisions such as whether to replicate and if so, according to what priority, or otherwise, store(-and-carry) and for how long storage should be allocated.

To sum up, the differences between the initial NREP approach and the extended version of NREP for the UMOBILE project are the following:

- **Communication based on interests**: Only users that expressed an interest on the same content receives updates for the service that they expressed interested. In UMOBILE, interest matching is provided via the Contextual Manager (which may obtain interest lists of peers directly via scanning, e.g., Wi-Fi Direct, or via applications).
- **Extension based on social-aware priorities**: We extended the number or parameters that are considered in the dissemination priorities. These priorities are detailed in Section 4.3.
- **Connectivity management based on social parameters**: In this work, in contrast with the initial proposal, we consider Wi-Fi Direct communication as

detailed in previous section. To manage these Wi-Fi Direct connections, we have to previously set up a Wi-Fi Direct group, which takes some time. Thus, we rely on the social parameters to prioritise Wi-FI Direct connectivity to those users that are closer to recipients instead of broadcasting the information to all users around without any preference.

4.1 NREP in the UMOBILE Architecture

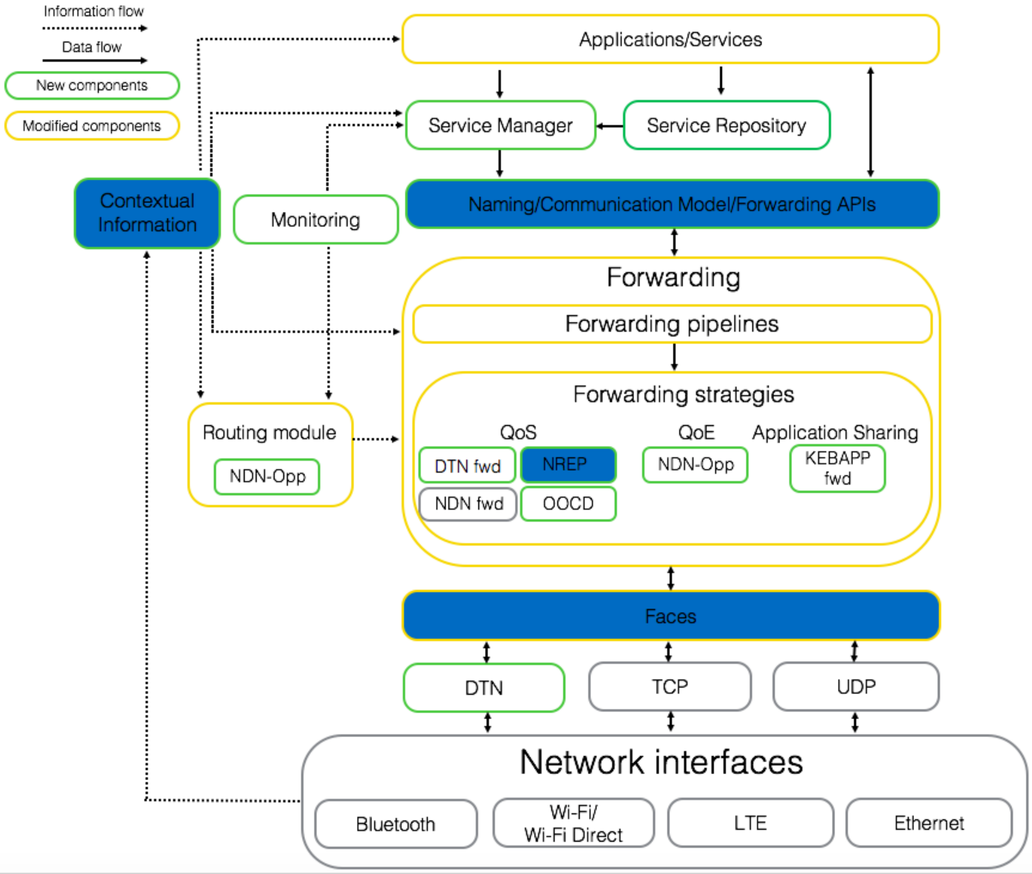

Figure 1. UMOBILE architecture and NREP role.

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In Figure 1 we can observe the set of modules that composes the UMOBILE architecture as has been detailed in Deliverable D3.1. In this figure, we can observe the set of modules that NREP is part of, and therefore they need to be modified in order to implement NREP. The modules are the following:

- **Naming scheme**: The naming scheme needs to represent the content prioritisation depending on how critical is the application/service. The namespace contains the name of the service representing the different priorities and the multiple attributes used to prioritise the different data. An example of the namespace is detailed in Section 4.2.
- **Content store**: The caching policy implements the prioritisation policies in order to replace first the content that is not important in terms of critical level. This caching policy is detailed in Section 4.4.
- **Application/services**: The application services should use the specific naming scheme in order to take benefit of the proposed scheme.
- **Forwarding engine**: The forwarding engine is modified in order to prioritise the critical content exchange when contacts between users occur. This forwarding engine follows the operation described in Section 4.3
- **Face manager**: The face manager is modified to take into account the contextual information to manage and prioritise connection establishment with those users socially closer to the recipient of the content or those users that will be able to better spread the content.
- **Contextual information**: We have specicifed interfaces between the contextual information module of the UMOBILE end-user service and the NREP modules in order to be able to use the contextual information to improve the priority information forwarding. These interfaces (social-aware priority interfaces) are detailed in the next section (4.1.1)

4.1.1 Social-aware Priority Interfaces

A key challenge in priority-based replication is to decide whether to drop or to assign a high-priority to a message that has already consumed a lot of resources and is therefore close to expiring or close to reaching the destination or that basically has not been relevant to its carrier for a long period of time. In order to assist in priority-based replication in UMOBILE, we have considered the module Contextual Manager, being developed in the context of task 4.2, WP4.

The UMOBILE Contextual Manager is a UMOBILE service that runs in background, and that captures information concerning the device affinity network (roaming patterns and peers over time and space) as well as concerning usage habits and interests (internal device information). Such capture is either performed directly via the MAC Layer (Wi-Fi Direct, Bluetooth) as well as via native UMOBILE applications which allow the user, e.g., to configure interests or other type of personal indicator preferences. For instance, an application can request a one-time configuration of categories of interests such as music, food, etc. Such meta-data is passed to the contextual manager, associated to the device UUID.

Metrics derived from such contextualization are then passed, upon demand or periodically, to other UMOBILE modules to assist in different network operational aspects (e.g., routing module; applications; NREP).

The Contextual Manager (which resides on the UMOBILE element “End-user Service”) interacts with NREP via the provisioning of specific utility functions that provide indicators of the social behavior of users to assist in a more efficient data dissemination.

As described in deliverable D3.1, D3.3, as well as D5.1 and D5.3, the Contextual Manager in UMOBILE performs contextualization derived from data that is either directly captured via multiple sensors (currently, Bluetooth and Wi-Fi interfaces) as well as via external sensing applications, such as PerSense Mobile Light.

A high-level illustration of the end-user Service as well as of the Contextual Manager and NREP interaction is represented in Figure 2.

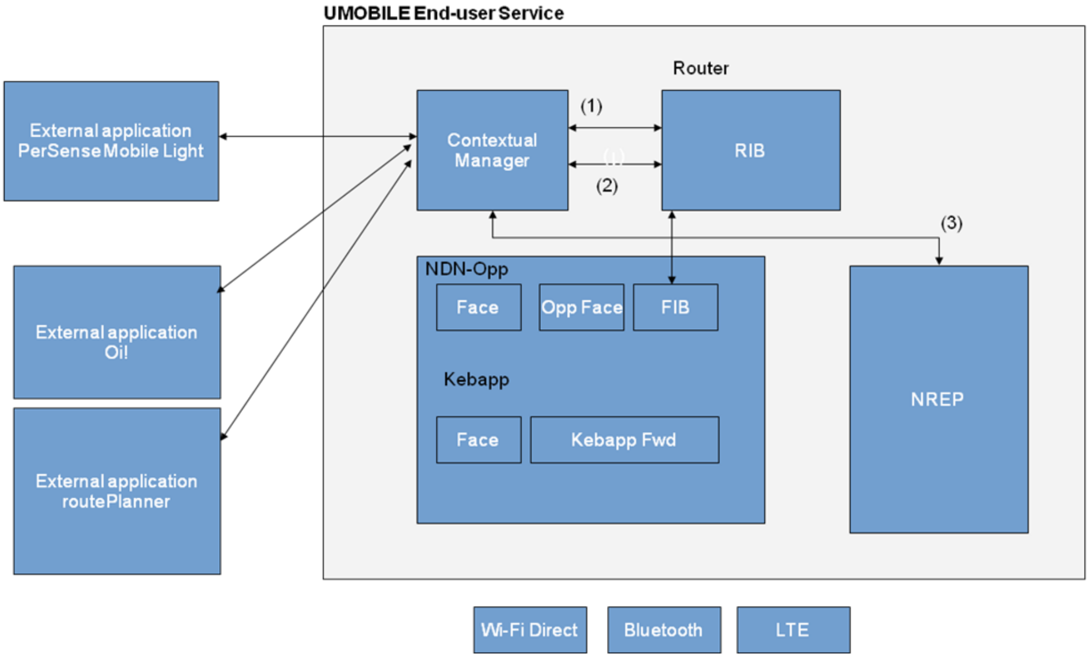

Figure 2: High-level representation of the UMOBILE end-user service. Interface (3) corresponds to social-aware prioritization fed into NREP by the Contextual Manager, on demand or periodically.

The interface between the Contextual Manager and NREP is bi-directional and has two different operational states:

- NREP can perform a request to the Contextual manager to get a set of priorities (indicators) for a specific time window.
- NREP can get (periodic) notifications for specific sets of indicators.

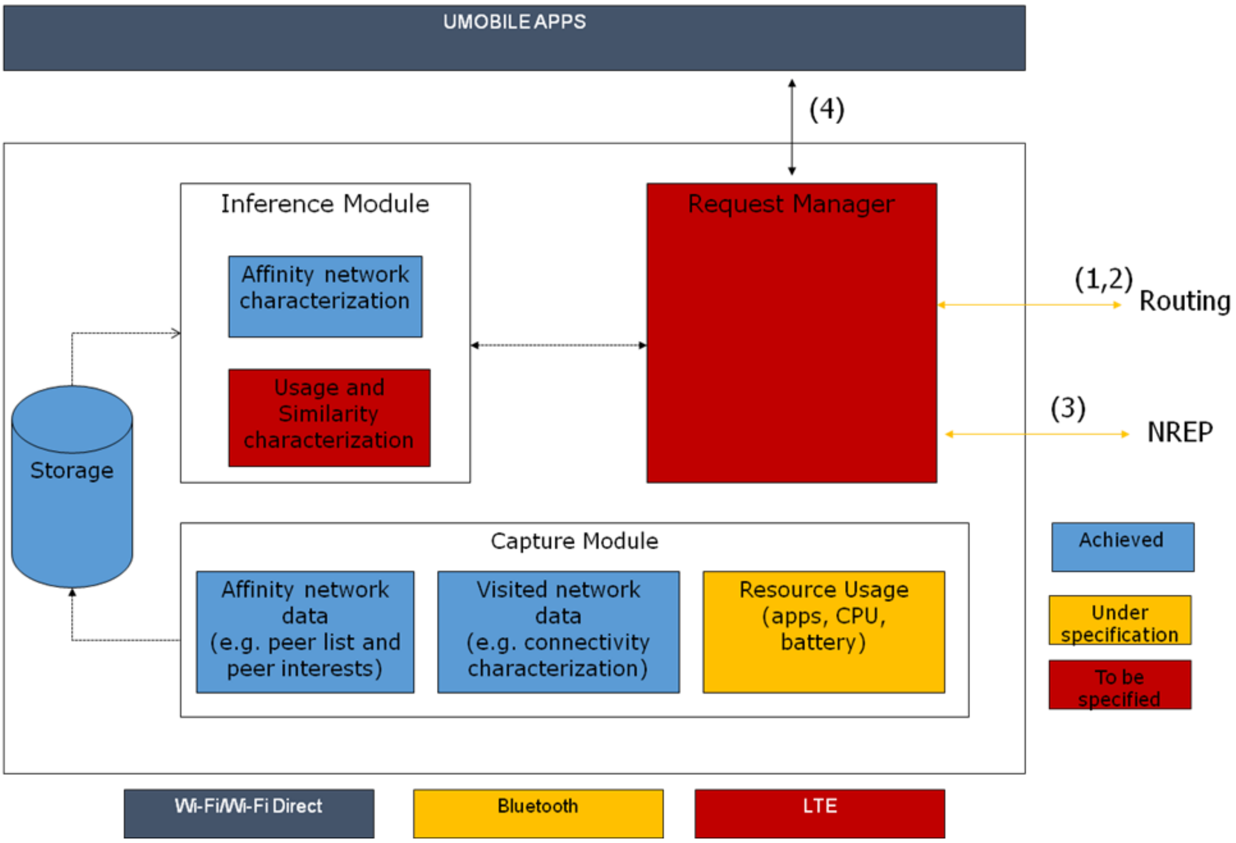

Figure 3: Contextual Manager status and interfaces towards NREP.

The data exchanged concerns social-aware priorities (refer to section 4.3). Indicators are periodically captured by the Contextual Manager either directly via Wi-Fi, Bluetooth, or via integration with external sensing applications, such as PerSense Mobile Light (PML); Oi!; Now@, etc. The Contextual Manager (CM)[4] holds four different interfaces towards other modules (two interfaces for the routing module; one interface for NREP; one interface for native applications). These two interfaces allow other modules to query or to obtain information from the CM. The type of information that any CM interface provides can be categorized into two main sets: i) **affinity network**

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[4] The Contextual Manager is being defined and implemented in the context of UMOBILE WP4, Task 4.2. The full specification will be provided in deliverable D4.5, month 36.

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characterization data; ii) usage and similarity characterization data. Affinity network information concerns, i.e., peer status over time and space as well as affinities (matches) between source nodes and peers. Indicators that can be provided and that concern usage and similarity characterization are built upon data collected internally (in the device).

4.2 Priorities and Namespace

As discussed earlier, the need for prioritisation in order to make efficient use of network resources and ensure that safety-critical messages get preferential access to network resources is of paramount importance in the aftermath of disasters or emergencies. Safety-critical messages must be given higher priority over other low-priority traffic when they compete for the same network resources. According to our initial design, the name-prefix is associated with a globally recognisable priority factor. For example, as shown in Table I, the NREP application is globally preset with the knowledge that the SOS name-prefix has higher priority than the chat name-prefix. Moreover, the messages can be linked to a temporal-validity value. This temporal-validity value can be represented as a time-to-die in absolute unix-time, e.g., *1387414134* which implies that the content is valid till *2013-12- 19T00:48:54*. Similarly, the space value, i.e., the area within which the data is valid can be represented by the following format *<type=circle;pos=x,y;radius=r>*, or *<type=rectangle, leftpos=x,y;height=h,breadth=b>* . Alternatively, the space value can be represented in the global map format, e.g., *country/state/city/*. In [5] a discussion is included whether these parameters should be included in the namespace or attached as attributes of the name. However, for simplicity, in this work we consider that all the parameters are included in the name. Below is an example list of priorities together with their characteristics in terms of space and time limitations.

- **High priority messages**: Messages calling for help could use the name-prefix SOS (see Table I). Such messages have to spread quickly and should live long enough until help is received. In order to minimise misuse (selfish behaviour), messages sent with this name-prefix should be smaller in size and the time-to-live should not be very long. Otherwise, it will be difficult to stop the message from spreading even after help has been received. Moreover, a long expiry time could imply that too many people end up responding to it, thereby overutilising scarce resources that could be used somewhere else. If no response is received within the stipulated time, the client can increase the time-to-live and send the message again. A challenge associated with this name-prefix is to find a means to stop the dissemination, once a particular team has responded to it to avoid multiple teams responding to a single SOS call. To deal with this challenge, one

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could apply TTR-like techniques [16] between the members of the rescue teams, in order to better organise and manage operations. Furthermore, messages from central state entities with instructions from first-responders (fire brigade, ambulance) to citizens need to spread to everyone and should not expire. Here, only the application residing on a limited number of authorised devices is allowed to send data with a suitable name-prefix such as Government, Police (see Table I). Messages notifying the arrival of rescue teams in an area at some fixed point in time to distribute first aid kits, water, food, etc. can be high priority too. People in the area should be informed and the message should be deleted after the rescue team has arrived.

- **Medium priority messages**: Messages from individuals or the government announcing the availability of food, water, etc. in a certain area should spread locally and be deleted after a period of time, as the resource will have been consumed. Similarly, messages on availability of shelter, electricity or communication capability available in an area should spread within that area, and need not expire since the shelter will be present for a long time. Such messages will have to be deleted only if conditions change, e.g., shelter is full.
- **Low priority messages**: Messages sent by individuals trying to get in touch with people in the area to get together and help each other are assigned lower priority. Such messages spread locally and normally can be deleted after delivery. These messages use the Chat name-prefix as shown in Table I and therefore receive lower priority compared to more important messages.

In the following table, we specify an example of different priorities with its related attributes that can be defined in the NREP system and used to give priority to emergency services over other services. We think we can use this set of name prefixes as an example of different applications that can be used in the UMOBILE platform.

Table 1: NREP original priority scheme.

Name-prefix	Priority	Time-to-live	Space	Authorizaiton	Recipient	Notes
SOS	High	Short	Closeby	All	First-responders	To use to ask for help
First-responders	High	Indefinite	Depends	First-responders	All	To inform all of rescue-teams arrival
Police	High	Depends	Depends	Police	Police members	To chat among themselves
Government	Medium	Indefinite	Area	Officials	All	To inform all of food-shelter, danger
Warning	Medium	Indefinite	All	All	First-responders	First-responders verify and publish to all
Safe	Medium	Short	All	All	Public / Family	To inform others they are safe
Chat	Low	Short	All	All	Public	To chat among each other

In NREP we devise a set of attributes that can be used to prioritise/relay content and are defined for each message:

- A priority level.
- A spatial scope, i.e., the geographical area outside which the message is no longer important.
- A temporal validity, i.e., a timer at whose expiry the content of the message is no longer useful.
- Recipient.

4.3 Social-aware Priorities

A key challenge in priority-based replication is to decide whether to drop or to assign a high-priority to a message that has already consumed a lot of resources and is therefore close to expiring or close to reaching the destination or that basically has not been relevant to its carrier for a long period of time. In order to assist in priority-based replication, we have considered the following approaches, based on the contextualization indicators that can be obtained via the Contextual Manager:

- **Resource level.** The prioritization takes into consideration a specific resource level for the device provided by the contextual manager, being the resources considered: storage; battery level. A concrete example is a device that, due to its centrality, is carrying 100 MB of UMOBILE data, corresponding to 80% of the data allowed to be carried by its user. While for battery, when the device reaches a specific level of energy consumption (e.g. battery level at 20%) then all subsequent messages shall be less important, and some may be discarded. This approach is computed periodically and locally, in a fully decentralized way.
- **Surround crowd density.** Here, surrounding networking conditions (number of peers; average contact duration) are combined to provide a cost on crowd

density. As explained in deliverable D3.3, the surrounding networking conditions can be retrieved and used to adapt not only routing decisions, as well as local data dissemination decisions (e.g. crowded urban area or sparse network). Crowd density is obtained using the contextual manager information provided about the Peer list (bluetooth and Wi-Fi Direct) at instant t or over time window T.

- **Social Strength.** Upon encounter, the devices exchange information concerning their social strength regarding the recipient of the content, following the computation of the social strength metric provided in the contextual manager and which is based on the SOCIO approach. The social strength metric used has been the Time-Evolving Contact Duration (TECD) [17], even though UMOBILE shall integrate (WP4, task 4.2) other metrics for the characterization of social interaction, not necessarily cumulative.
- **Individual Interest-based.** Upon encounter and before data exchange devices negotiate interest on specific tags. For instance, if both devices are interested in Government then any content with such tagging will be prioritized; if not, the content priority will be lower than other preferred content. This information can be derived from the list of applications installed on the device, but also from the user information inferred from the contextual manager about preferred visited network and/or geo-location, type (category) of preferred application (e.g. most used over time window T), or time spent per application category (e.g. per day).

4.4 Operation

In NREP we consider that there are three types of nodes: *source nodes* that origins the information (e.g., emergency alert from a user), *relay node*s that retransmits information to other users (e.g., users nearby relaying the information), and *destination nodes* that act as passive nodes that only receives the information (e.g., emergency services, first responders).

In the following we detail them:

- **Source nodes:** are the source/providers of the messages updates. Their job is to disseminate the content further to users that have the same application installed on their device, or are subscribed to the emergency service channel. Source nodes are theoretically a small percentage of nodes.
- **Destination nodes:** are passive nodes that have a number of applications installed on their device and expect to receive updates on those while roaming. Local D2D data transfers take place when a source node meets a destination node whose application or channel has outdated content.

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- **Relay nodes:** are destination nodes that can become (act like) source nodes once they get updated. This mode of accelerates significantly the distribution of content in the mobile, D2D domain. The amount of time that destination nodes act as relay nodes is subject to a number of parameters, which we evaluate in Section 5.

4.5 Content dissemination

First of all, NREP uses the service discovery mechanism described in Section 3, in order to discover users nearby that share or are interested the same service. When a destination node is nearby a source or relay node using the same application, this one is added to the list of users ready to be connected. This way, users only share information when they share the same interests. Every time there is a user in the list and the source/relay node has some information to send for that application, within the time and spatial validity, it establishes a new connection with this user and starts the transmission. Before the transmission, users check that the destination node did not received the content yet. If not, the source/relay node sends the information to the destination node. After a transmission, or when it is detected that the destination node is no longer in the area, the destination node is removed from the list of users ready to be connected.

When multiple nodes are in a crowded area, the list of users ready to be connected can be large. Connections are ordered by priority of its users applications, depending on the weight of the content that is detailed below. In order to prioritise the connections to those users that are going to relay the message better, after ordering the list by users that want to share the most important content, we also order the list of users by social strength to the destination of the message (e.g., the users who are more probable to pass by the police station) for those users interested in the same application. In case that users have the same social strength, or this is null because they had no previous contact with the destination, connections are ordered by other values defining the level of resources available, such as the battery level or the data allowed.

4.6. Content prioritisation

Each device assigns a weight *w* to all of the messages it holds and forwards them in decreasing order of *w*. This weight is calculated as a function of the distance from the origin of the message, the residual time validity, and its priority.

$$w =\propto f_d(d) + \beta f_t(t) + \gamma p \quad \text{(Eq. 1)}$$

where $f_d\colon \mathbb{R}^+ \rightarrow [0,1]$ is a monotonically decreasing function of the distance from the origin of the message, $f_t\colon \mathbb{R}^+ \rightarrow [0,1]$ is a monotonically decreasing function of the time elapsed since the message creation and $p\epsilon[0,1]$ is a value expressing the priority of the message and $\propto, \beta, \gamma\epsilon[0,1]$ with $\propto + \beta + \gamma = 1$

A key challenge in priority-based replication is to decide whether to drop or to assign a high-priority to a message that has already consumed a lot of resources and is therefore close to expiring or close to reaching the destination. This would be in contrast to a message that was just created and therefore has a high temporal validity and/or reach. Based on this decision $f_d$and $f_t$in Eq. 1 are either monotonically increasing or decreasing. Each mobile device may also decide whether or not to forward messages on the basis of its residual battery life. In fact, if battery life is scarce, a device may decide to only forward most important messages or no messages at all.

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5 Performance Evaluation

For the evaluation of the proposed NREP mechanism we extended the ONE simulator [18]. ONE is a discrete event simulator for opportunistic network environments, and is capable of generating node movements using various models, routing messages using different DTN routing schemes and provides interfaces for application level extension. The scenario chosen for assessment was that of a busy city environment, namely Helsinki city center, with a fixed population of users carrying a mobile device capable of D2D connectivity and support for multiple smartphone applications.

We have used a variety of movement models/patterns (included in the ONE simulator) in order to assess the efficiency of the proposed approach to mobile content dissemination. We have used the Helsinki city population and city centre as the default urban environment (area of size equal to 8.3km x 7.3km). By default, we assume that the population of the destination nodes is equal to D = 1000.

Destination nodes are configured as follows: out of the 1000 nodes 20% are assumed to be tourists. Tourists choose random destinations (either total random points in the map or one of the seven “points of interest” (i.e., tourist attractions) in the city centre) to which they travel following the shortest path and wait randomly 2-15 minutes. The majority of the destination nodes, i.e., the remaining 80%, are assigned the working day movement model [19], which allows them to travel to designated office spaces on the map and travel for other evening activities later in the day. All nodes start at their base/home and travel to their office, either directly by car (50% of nodes) or by bus (remaining 50%). Once they reach the office, they spend 7 hours there and at the end of the office day there is a 50% chance the node will go for an “evening activity”.

For comparison purposes we have extended the ONE simulator with an application- and priority-agnostic dissemination. According to this last scheme, source nodes blindly send blanket update messages to nodes they encounter without prioritising content or checking whether the encountered node has the latest update or not. Effectively, this scheme imitates the behaviour of the “Floating Content” concept [21], where distance vector is set to infinity (i.e., the borders of the city). In the following, we denote this distribution method as floatingContent (fltCTN). Intuitively, and as we show later in our evaluation results, it is clear that floatingContent introduces huge amount of duplicate messages exchanged between nodes. To make the comparison more pragmatic, we have built a combination of the Floating Content concept with the “First Contact” dissemination strategy [20]. Single contact relay or First Contact [16] is a well-known traditional DTN routing and replication strategy, according to which nodes forward the messages they have to the first node they encounter only. The combination of First

Contact with Floating Content effectively reduces the number of replicas in the system in an attempt to reduce duplicate messages and overhead.

The parameters used in the evaluation are summarized in the following table:

Table 2: Evaluation parameters.

Parameter	Value
WiFI Direct Speed	30 Mbps
Range	60 m
Default buffer size	100MB
Nodes	1000
Area	8300 m x 7300 m
Message size	5MB

5.1 Impact of the relay time

As a first evaluation, initially, we examine the impact of the relay time *t* in the performance of the *NREP* replication mechanism dissemination mechanisms. In this case, we set up a population of the source nodes equal to S = 50 (although we also experiment with different ratios of Source-Destination nodes in next section). The distribution of source nodes is as follows: out of the 50 nodes, we assume that 18 are buses that follow predefined routes, whereas the rest nodes (i.e., 32 in the default scenario) are assumed to be users that follow the working day movement model [19].

Relay nodes are active only certain time *t* and, in this evaluation, we gauge the performance using different relaying times. In this first case, all users have multiple applications installed (services) following a Pareto distribution by popularity, but all users have at least one application installed (emergency application). In this case, we consider all applications have the same priority. The temporal validity scope is the time of 1 period interval (1h) and the spatial scope is the whole area. Relay nodes and destination nodes are the same (i.e, destination nodes relay information for a certain amount of time). Here, the time anchor is set to the application update period/interval equal to 1 hour.

In Fig 4,5 and 6 the relay time t is the amount of time that each relay node is active. We examine relay times that vary from t=0 (no relay) to t=3600 (1-hour relay), which we assume as the default update period of each application. Note that the plots are depicted as error bars, where the error bars correspond to upper and lower bound results for the most and least popular application, respectively and not the typical standard deviation.

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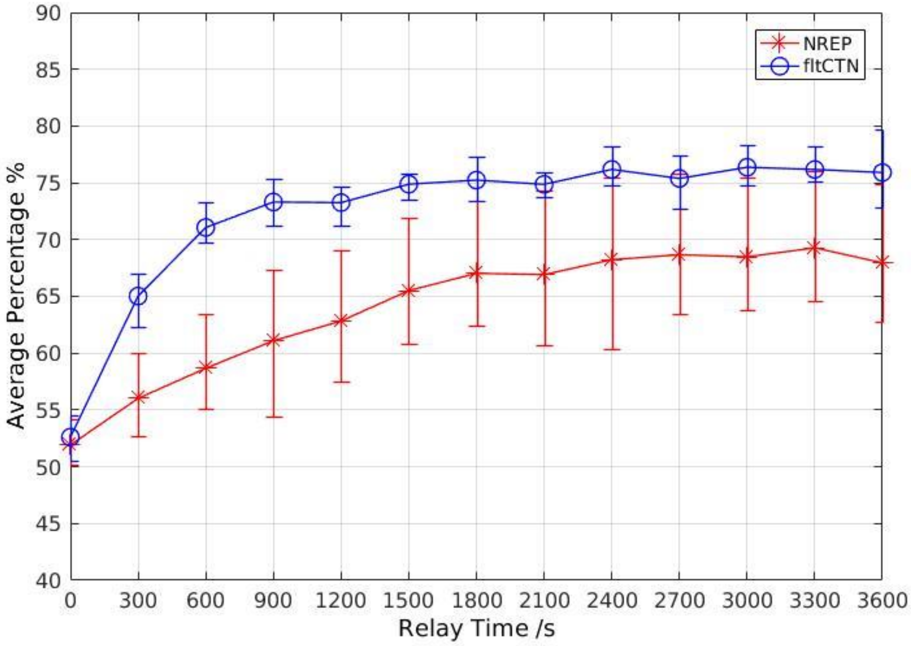

Figure 4. Percentage of Destination nodes with updated content with the impact of the relay time

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From the Satisfaction ratio plot in Fig. 4, we observe that when only source nodes disseminate content (i.e., no Relaying) already half of the destination nodes manage to retrieve the updated content. When destination nodes start to relay the received content, even for a very small amount of time (i.e., 5-15 minutes), the satisfaction increases by up to an extra 40%. This is also obvious from the Relayed content plot (Fig 5) where we see that the total number of messages distributed by the relay nodes can reach up to 80% of the total transmitted messages in the floatingContent case and 50% in the NREP case. This is because the floatingContent solution relays content for any application, not only the applications installed, relaying more content that NREP solution.

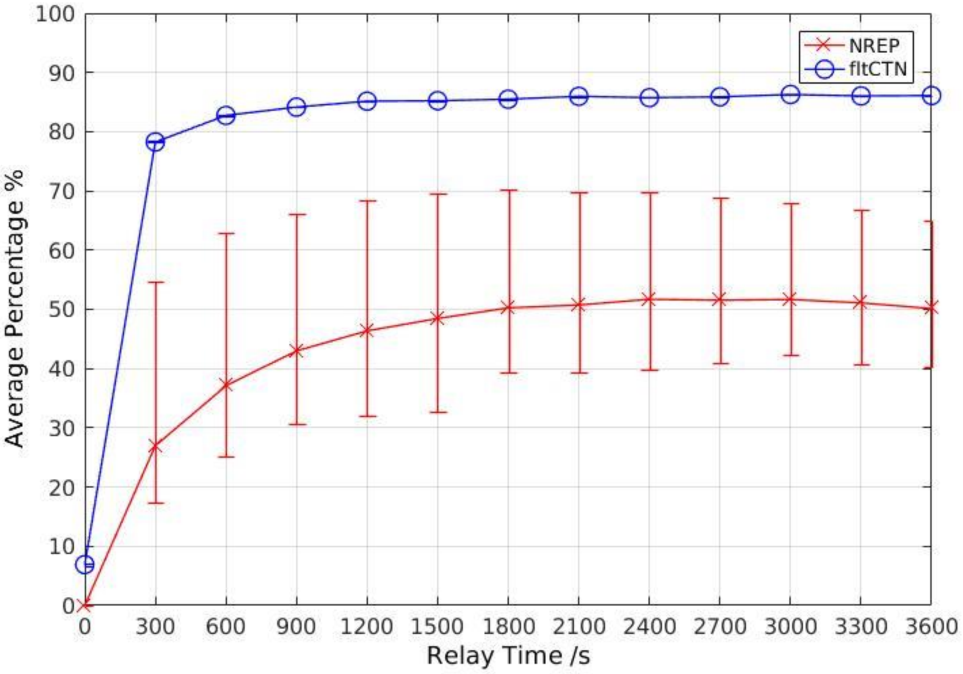

Figure 5. Percentage of messages sent by relay nodes over all transmitted messages with the impact of the relay time

Increasing the relay time to more than 15 minutes (900 secs onwards) brings no substantial gain in terms of satisfied users. This result illustrates the fact that while some users move in the city centre and therefore can interact and receive updates, some others remain in non-reachable areas, e.g., offices or outskirts of the city. This result serves as an upper bound of the performance of the examined content dissemination mechanisms, given the specific settings.

Comparing the performance of NREP connectivity with information-agnostic floatingContent in Fig. 4, we observe that the fltCDN scheme performs around 15% better in terms of satisfaction ratio. However, as expected with this “aggressive” approach, it creates at least four times more redundant transmissions (i.e., overhead), as shown in the Message Overhead plot in Figure 6. As expected this, effectively, flooding behaviour has severe consequences in terms of the energy spent by user devices, as we will see later in this section.

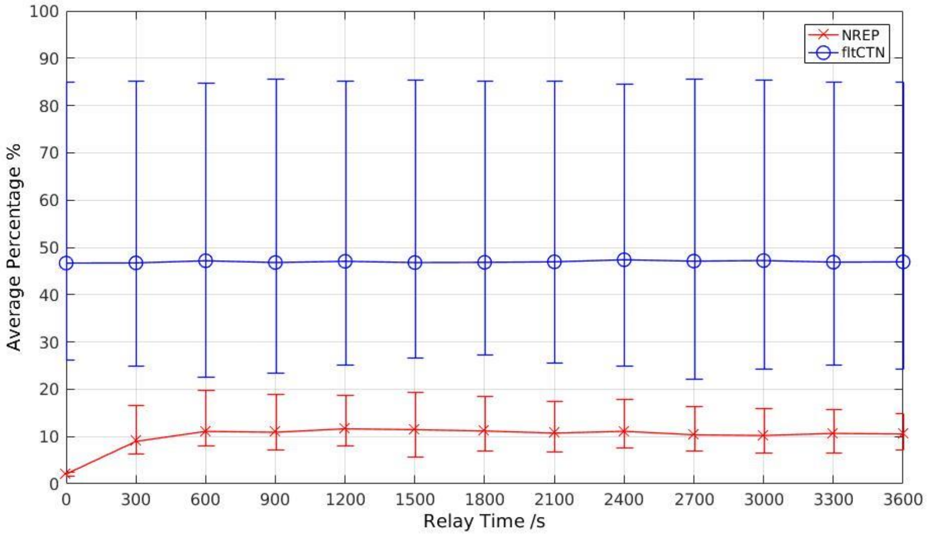

Figure 6. Percentage of overhead received messages with the impact of the relay time

In Figure 6 we observe that NREP introduce only around 20% of message overhead for the most popular application, whereas in the floatingContent case almost 90% of the transmitted messages for that particular application is redundant.

5.2 Impact of the priorities

In this second set of evaluations we evaluated the same scenario defining multiple services with different priorities and parameters. The service defined are the following:

Table 3: Defined services for the evaluation

Service	Priority	Time-to-live	Generation interval	Space	Recipient
SOS	High	60 min	60 min	Everywhere	First-responders
Government	Medium	35 min	60 min	300 meters	All
Chat	Low	15 min	60 min	Everywhere	All

In this case, we evaluated 3 different services with different priorities: a high priority service emulation SOS messages, a medium priority service emulating safety messages from the government and a low priority service emulating a chat service. The simulation time is 24 hours and the generation interval of the messages, time-to-live and space values are the specified in Table 3. SOS recipient are the first responders (e.g., police station) and for the rest of the services is any node interested on it. In this scenario, we set up only 3 source nodes, randomly placed in the map, one for each service. The first-responder node is a single node situated in the middle of the scenario and at 1 km far from the SOS source node. We consider that all messages have the same size of 5MB. The number of destination nodes is 200 nodes. The relay nodes are always active (they relay message all the time) in this set of simulations.

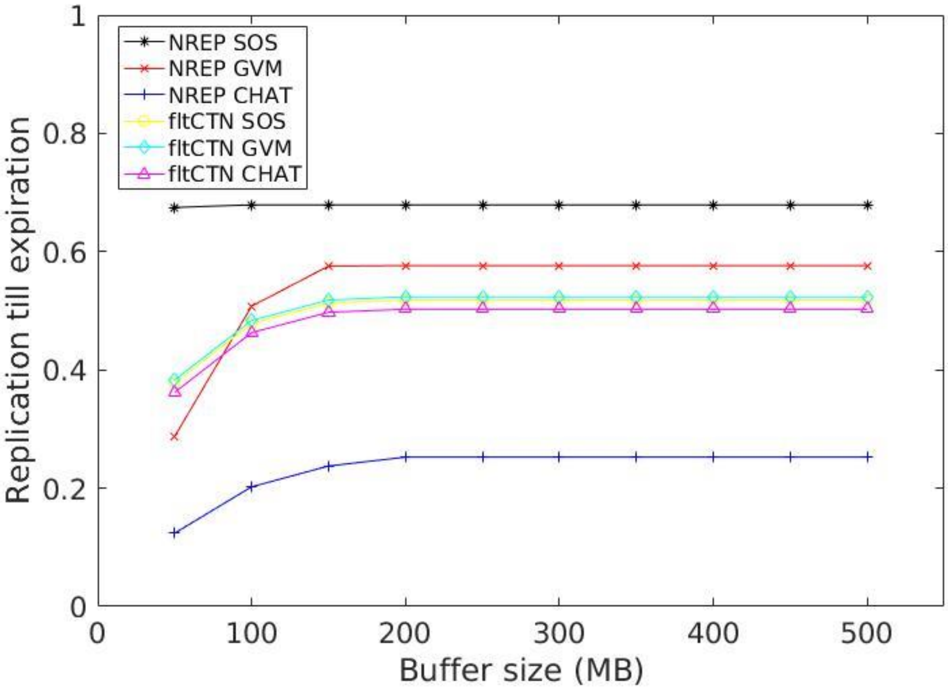

Figure 7. Percentage of users that receive messages before the expiration

The results in Fig. 7 show the percentage of users that are receiving messages for each expiration interval. We can see that NREP achieves considerably better performance for high-priority messages (SOS), while its performance drops substantially for low-priority messages (Fig. 1b). The longer a message stays in the network (i.e., some node's memory), the higher the probability that it will inform more users. It also affects that we send first SOS messages before other messages with lower priority. Instead, fltCTN appear to have similar performance in all cases. For big buffer size (higher than 200MB) the difference between NREP and fltCTN is around 40% (from 50% to 70% approx.). The difference is more clearly shown in for small buffers (between 50MB and 100MB) where this difference is increased to a 60%. There, we see that inline with our design principles, NREP transmits more messages of higher priorities, while it leaves less space and transmits less messages of lower priority services.

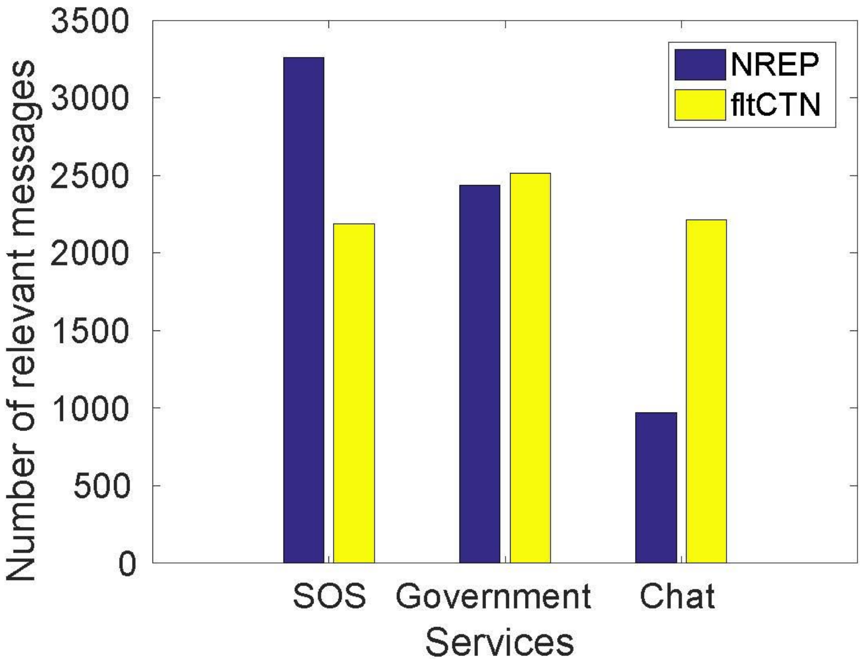

Figure 8. Number of messages replicated per each service during the simulation

In accordance with Figure 7, in Figure 8 we show the number of total messages transmitted in the simulation for both approaches, NREP and fltCTN. The maximum number of messages that can be transmitted is 4800, considering that we have 200 nodes and 24 update intervals, and we do not transmit content to the users that have already the last message. According to the figure we see that the numbers of Chat messages is only a small part of the SOS messages relayed using NREP, while using fltCTN the number of messages is irrelevant to the priority of the service and the replication rate is close to the half of the users.

In Table 4 we show the average delay for the recipient node (police station) and the number of SOS messages received during the simulation. The total number of messages that can be received is up to 24, one each hour.

Table 4: Received messages for SOS services

Approach	Avg delay (sec)	Messages received
NREP	2251	22
fltCTN	6147	13

In the table, we can observe, that using NREP the number of messages received by the police station is higher. This is due, using NREP less SOS messages are dropped and therefore there is a higher probability that these messages will arrive to the recipient. Also, the average delay for the messages that arrive to the recipient is lower. This is because we prioritise the contacts with those users that are frequently in contact to the recipient using the social strength parameter. Therefore, SOS messages will arrive faster to the police using NREP.

5.3 Impact on Energy Consumption and Battery Depletion

Last, but certainly not least, we look into the energy consumption of user-operated D2D. Energy is the price paid by the system in order to disseminate content in a D2D manner and therefore, cannot afford to be overlooked in our feasibility study.

In Table 5 and 6 we show preliminary results using real devices (Galaxy Tab A tablet and Samsung Note 3 smartphone) and transmitting different file sizes using Wi-Fi Direct. These results are obtained with two static devices separated by around 10 meters and with a RSSI value close to -50dbm. We carried out a set of experiments using 5 MB, 50 MB and 100 MB of exchanged files and we extrapolated these results to the number of messages sent by source and relay nodes using the NREP and floatingContent mechanisms during an update interval of 1 hour as in Section 5.1. In floatingContent mechanism, each source node transmits between 660-785 messages during one update interval (i.e., 660 messages in the 1 hour relay case and 785 in the no relay scenario), whereas each relay node transmits up to 210 messages (i.e., 1 hour relay case), including the overhead messages. The corresponding number of transmitted messages in the NREP mechanism are 41-62 messages for the source nodes and up to 3 messages

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for the relay ones. We also extrapolated from this energy consumption the percentage of battery consumed using a tablet (i.e., 7000 mAh/25.9Wh capacity) or using a smartphone (i.e., 3200 mAh/12.4Wh capacity). The energy consumed by the Wi-Fi Direct application is measured using the Trepn Profiler tool [22].

Table 5. source nodes energy consumption results. summary of 1 hour, nrep: 41-62 msgs, floatingcontent: 660-785 msgs

Message Size:		**5 MB**	**50 MB**	**100 MB**
NREP	mWh	106.6-161.2	179.99-272.18	212.38-321.16
	% Battery phone	0.86-1.3	1.45-2.19	1.71-2.59
	% Battery tablet	0.41-0.62	0.69-1.05	0.82-1.24
floatingContent	mWh	1716-2041	2897.4-3446.15	3418.8-4066.3
	% Battery phone	13.83-16.45	23.36-27.79	27.57-32.79
	% Battery tablet	6.62-7.88	11.18-13.3	13.2-15.7

Table 6. Relay nodes energy consumption results. Summary of 1 hour, nrep: 3 msgs, floatingcontent: 210 msgs

Message Size:		**5 MB**	**50 MB**	**100 MB**
NREP	mWh	7.8	13.17	15.54
	% Battery phone	0.06	0.1	0.12
	% Battery tablet	0.03	0.05	0.06
floatingContent	mWh	546	921.9	1087.8
	% Battery phone	4.4	7.43	8.77
	% Battery tablet	2.1	3.55	4.2

From Table 5 and 6, we can observe that the energy consumption for the NREP source nodes goes from 106.6 mWh in the best case (41 messages sent) when sending 5 MB messages, to 321.16 mWh worst case (62 messages) when sending 100 MB (including the energy required for the group formation mentioned in Section 3). This means the percentage of the battery consumed is between 0.86% and 2.59% for a smartphone, and between 0.41% and 1.24% for a tablet. In case of relay nodes, the energy consumption goes from 7.8 to 15.54 mWh, meaning from 0.06% to 0.12% of the battery for a smartphone and 0.03% to 0.06% for a tablet, respectively. From this analysis we can consider that energy consumption is not an issue in the case of the NREP case even if we assume large update messages. However, in the floatingContent case the non-application aware content delivery and the relatively increased message overhead will deplete quite fast the battery of a user's device. For example, in Table 5 we see that smartphones can spend up to 32.79% of the battery, or tablets can spend up to a 15.7% of the battery, in a single update interval (i.e, 1-hour). This means that a more sophisticated content aware dissemination mechanism is required in order not to discourage users from participating in D2D communications.

The results obtained in this energy consumption analysis, despite being preliminary with simple tests, are in line with the results presented in [23]. In [23] the authors report that an average smartphone can transmit up to 44GB of data before depleting the battery, with an average consumption of a 1 J/MB (i.e., 1.38 mWh for a 5MB file) in a walking speed mobility scenario.

6 Conclusions

In this document, we defined the name-based prioritization and replication scheme in fragmented networks during disasters and/or emergency situations for the UMOBILE project. Our scheme borrows ideas from the Floating Content [24] concept as well as from offline pub/sub systems that work in infrastructureless environments (e.g., Twimight [25]), but enhances them in order to work in a name-based, ICN environment, which provides benefits over IP-based, host-centric networks. We extended our previous work done with the name-based prioritization and replication scheme with new social parameters (i.e., social strength, resources, users interests, crowd density) and we integrated the solution into the UMOBILE architecture by specifying new modules and interfaces. We evaluated the scheme in a realistic mobility scenario and we have shown that indeed higher priority messages get disseminated to more nodes (up to 60% more) in the network, which might be of vital importance in case of disaster/emergency.

Despite NREP has only been evaluated by means of simulation in this deliverable, it will be implemented in Android smartphones within the WP5 “Overall platform integration and validation” for the proof-of-concept (Task 5.3 -M36-), and a final demo is expected, based on the specification provided in this deliverable.

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