A novel ICN-based communication bus for Intelligent Transportation Systems

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***Abstract*—This work presents a novel information-centric communication bus for Intelligent Transportation Systems, namely BONVOYAGE Communication System. Based on the Internames principle (i.e., an evolution of the well-known Information-Centric Networking paradigm), it offers a scalable and distributed dissemination of real-time contents through standardized interfaces, request-response and publish-subscribe schema, while ensuring interoperability across borders. To prove its suitability in real scenarios, the main functionalities of the BONVOYAGE Communication System (including namespace, data processing, and caching) have been properly designed and characterized in order to effectively disseminate travel-centric data (i.e. contents of interest of Intelligent Transportation Systems) formatted according to DATEX II specifications. Experimental tests demonstrate that the proposed solution outperforms baseline dissemination mechanisms in terms of processing complexity, communication latencies, and bandwidth consumption.**

***Index Terms*—Intelligent Transportation System, Information-Centric Networking, Internames, experimental tests**

I. Introduction

Recently, many research and standardization activities are emerging to motivate and stimulate the adoption of Information-Centric Networking (ICN) in concrete application domains [1]. With reference to the Intelligent Transportation System (ITS), for instance, most of the contributions focus on vehicular networks and address different aspects, including namespace [2][3], caching strategies [4][5], routing-by-name algorithms [2][3],[5]-[7], optimized delivery of data [3]-[9], routing algorithms [5][6][7], protocol stack implementation [10], and the analysis of communication primitives [4]. More general contributions are presented in [11] and [12]. The work presented in [11] proposes a general purpose namespace and describes the usage of ICN communication primitives in different ITS scenarios. The key functionalities of the ICN protocol architecture are investigated in [12] for smart parking, traffic monitoring, and control services.

The Directive 2010/40/EU defined a legal framework for developing specifications to make ITS platforms interoperable across heterogeneous organizations [13]. Among the priority actions taken, there is the need to provide European-wide real-time traffic information, free of charge for users. For sure, ICN communication primitives could effectively support the dissemination of travel-centric contents in advanced and large scale ITS platforms. But, none of the scientific contributions listed before provides consolidated methodologies for reaching this challenging goal.

By jointly leveraging European directives and ICN functionalities, the work presented herein proposes a novel ICN-based communication bus enabling advanced ITS services in heterogeneous network architectures, namely BONVOYAGE Communication System. Developed in the context of the European H2020 BONVOYAGE project [14], it is built on top of the *Internames* principle [15], that is an emerging network architecture evolving from ICN and allowing name-to-name communications across heterogeneous networks. The designed and implemented platform deals with each atomic travel-centric information as a unique content, identified through a realm-based, geo-referenced, and hierarchical namespace (see Section III). Moreover, standardized interfaces (embracing *front-end* and *networking* APIs), for exchanging such contents through request-response and publish-subscribe schema.

To demonstrate the usage of the BONVOYAGE Communication System in concrete scenarios, the dissemination of real-time information exposed by Norwegian Public Road Administration (NPRA) and formatted according to the well-known DATEX II standard[1] is investigated. As the baseline usage of DATEX II data is extremely resource consuming, a customized namespace, processing of DATEX II data, and an optimized caching strategy are conceived in order to properly address the real-time requirements of ITS applications. Furthermore, a preliminary experimental performance assessment is conducted to show the advantages offered by the proposed approach against the baseline one, as well as to highlight its ability to reach good performance in terms of communication latencies and bandwidth consumption.

The rest of the paper is organized as follows: Section II provides an overview of the BONVOYAGE Communication System and motivates its adoption in the dissemination of travel-centric data formatted according to DATEX II specifications. Then, technical details of the envisioned solution are deeply discussed in Section III. Experimental tests and preliminary performance results are presented in Section IV. Finally, Section V draws the conclusions and provides some hints on future activities.

II. The BONVOYAGE Communication System

The BONVOYAGE Communication System was developed in the context of the European H2020 BONVOYAGE project,

[1] http://www.datex2.eu/

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addressing the design, the development, and the test of a service platform optimizing multimodal and door-to-door transport of both passengers and goods [14]. Specifically, BONVOYAGE intends to leverage all the potentials of the ICN communication paradigm for disseminating static, real-time, and travel-centric contents, properly formatted according to well-known standards, such as General Transit Feed Specification (GTFS)[2] and DATEX II, just to name a few. To this end, it formulates two main services: data discovery and data dissemination. From one hand, data discovery is done through a distributed spatial database, namely OpenGeoBase (OGB) [16]. OGB uses ICN functionalities for different purposes, i.e., routing-by-name to dispatch queries and insertions, in-network caching to accelerate queries, and data-centric security to implement secure multi-tenancy. On the other hand, data dissemination is a service offered by the BONVOYAGE Communication System, which is the solution described in this work.

A. Usage and motivations

The BONVOYAGE Communication System can be used to disseminate any kind of contents. Nevertheless, to give a concrete example (and without loss of generality), this paper technically demonstrates how the BONVOYAGE Communication System becomes a suitable solution for the dissemination of travel-centric data formatted according to the DATEX II standard. Specifically, it represents one of the outcome of the standardization process related to Delivering European Transport Policy. It allows to expose travel-centric information through XML files. Possible information include data related to traffic conditions, data coming from different sensors on the roads (like weather monitoring stations), and Closed Circuit TeleVision (CCTV).

At the time of this writing (i.e., without the BONVOYAGE Communication System), a user interested in retrieving DATEX II contents referring to a specific geographical area must perform the following tasks: (1) periodically download all the files from the remote web server, (2) process them, (3) identify updates, if any, and (4) extract only the information of interest. Unfortunately, these operation are extremely resource consuming. In addition, considering that the percentage of information update for each XML file is, on average, always less than 10%, these operations are even more inefficient.

Fortunately, each DATEX II record has geographical information. Therefore, it is possible to extract travel-centric contents from each XML file, identifying single pieces of information, and use them in the BONVOYAGE Communication System. As a consequence, a customized processing of original DATEX II files offers the possibility to make optimized geo-referenced and information-centric queries, retrieve a specific selection of DATEX II data exposed by the remote server, as well as collect future updates through an efficient publish-subscribe mechanism. Technical details related to the namespace design, the processing of original DATEX II data, networking protocols, and caching algorithms are discussed in the next Section.

B. Network architecture

Thanks to the wide diffusion of several ICN implementations, the Internet is evolving to an heterogeneous structure. The main goal of the communication bus presented in this paper is to disseminate contents across heterogeneous network architectures, made up by different *realms* that implements different communication protocols. To this end, the conceived communication bus leverages and properly extends *Internames* which is a novel ICN architecture which allows name-to-name communication between realms with different networking protocols. Particularly, name-based identification is possible also for devices, services and users, as well as for contents [15]. The core network of Internames is based on one of the most used ICN implementation, namely Named-Data Networking (NDN) [17][18], deployed as an overlay network. As discussed in [15], Internames is in charge of offering low-level networking primitives for enabling the interaction among Internet Protocol (IP) and NDN network realms.

Figure 1 shows the whole architecture and the involved entities. Named Routers (NRs) act as border routers connecting two, or more, network realms, enabling specific network interfaces depending on the protocol used in each realm, i.e. IP or NDN. The Name Resolution Service (NRS) is the main entity of the Internames architecture; it is in charge of handling the inter-realm routing operations (as discussed in [15]). The Internames Rendezvous Node (IRN) is a new entity added to Internames. Specifically, it handles the publish-subscribe functionalities. Given their peculiar functionalities, it is important to underline that IRN and NRS are decentralized entities working among the different realms[3]. Data Consumers are end users willing to retrieve travel-centric information for planning and optimizing transportation services, thus providing real-time optimal-path finding. Data Producers, instead, could be either public or private transport operators providing information regarding heterogeneous candidate means of transportations, such as bus, train, or airplanes. End users interact with the BONVOYAGE Communication System by using standardized interfaces, offered by Consumer Proxy and Producer Proxy, which provide network access points to the Core Network. Logical nodes interact with each other using a set of *networking APIs*, exposed through a distributed middleware layer, presented in its preliminary formulation in [19]. Specifically, the middleware maps high layer requests to a set of low level communication messages (i.e., HTTP requests and responses for the IP realm; INTEREST and DATA packets within the NDN realm). Consumer Proxy and Producer Proxy expose a set of *front-end APIs*, allowing Data Consumers and Data Producers to interact with the platform through a standardized interface.

[2]https://developers.google.com/transit/gtfs

[3]The distribution mechanism is out of scope of the present work

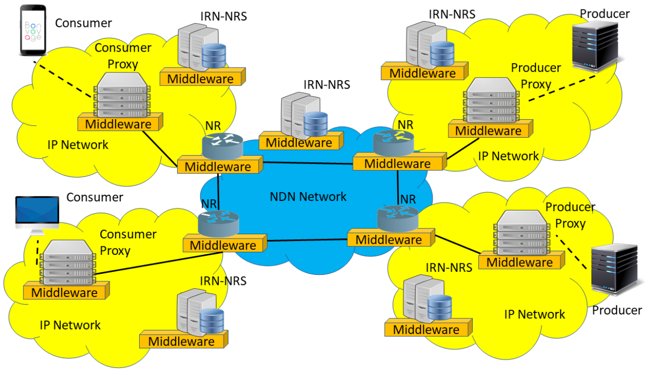


Fig. 1. The BONVOYAGE Communication System.

III. Technical details

A. Namespace

The BONVOYAGE Communication System adopts a realm-based, geo-referenced, and hierarchical namespace, as described in Figure 2.

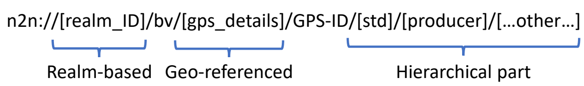


Fig. 2. Namespace structure

Names start with a string identifying the realm where the Data Producer is located (i.e., $[realm\_ID]$). This information is used by Internames to perform inter-realm routing operations. The string bv indicates that the considered contents are generated in the BONVOYAGE environment. In line with the OpenGeoBase [16] approach, travel-centric contents can be fetched according to their geographical information. This implies a spatial indexing of available contents through a layered grid, aligned with world's parallels and meridians. Grid regions are called *tiles* and present a geographical extension of $100km^2$. Therefore, the two Global Positioning System (GPS) points provided in $[gps\_details]$ identify a specific tile of a layered grid, where the content belongs to. The remaining part of the namespace is used to carry information about the standard adopted to expose the considered travel-centric data (i.e., $[std]$), the Data Producer (i.e., $[producer]$), and any other characteristic details (i.e., $[..other...]$). For example, by focusing on a tile whose low-left corner has GPS coordinates equal to (latitude = 59.9, longitude = 10.7), the names associated to corresponding DATEX II contents are:

- n2n://polibaNet/bv/10/59/79/GPS-ID/datexii/npra/weathersite
- n2n://polibaNet/bv/10/59/79/GPS-ID/datexii/npra/situation
- n2n://polibaNet/bv/10/59/79/GPS-ID/datexii/npra/weatherdata
- n2n://polibaNet/bv/10/59/79/GPS-ID/datexii/npra/cctv

Definitively, the naming is able to reference a specific content in a precise tile in the grid.

B. Type of contents and related format

For each of travel-centric name, two different contents are made available: initial contents (namely *INIT*) and updated contents (namely *UPDATE*). The Data Producer generates INIT and UPDATE data. INIT contents are those that must be delivered to the Data Consumer, in a synchronous way, as soon it joins the platform and performs a request or a subscription. This first delivery phase is aimed at providing both static data and initial ones. Both of them are related to initial values but they cover values of the contents that are not going to change (frequently) over time. UPDATE contents, instead, are delivered to subscribers asynchronously, as soon as they are generated, and include any modification to data currently produced by the Data Producer.

The messages exchanged in the WebSocket sessions are encoded as JavaScript Object Notation (JSON) objects with a custom format. In particular, they include three fields: *header*, *type* and *content*. The *header* field contains information about the API to be used (messages sent by users) or the name which data refers to (messages delivered from Consumer Proxy to users). This part is mandatory in order to disambiguate communications and properly address the message to the user/consumer/application which asked for it. The *type* field specifies the type of the message payload (data or log information). Finally, the *content* field is the message payload, which encapsulate the travel-centric content or log messages for error handling.

C. Front-end APIs

The *front-end APIs* expose Internames services to end users through standardized interfaces. In details, both communication schema leverage the secure WebSocket technology, useful to establish asynchronous and bi-directional data exchange. In summary, *front-end Application Programming Interfaces (APIs)* include: $Producer\_Publish\_Init$, $Producer\_Publish\_Update$, $Consumer\_Request$, and $Consumer\_Subscribe$. With reference to the types of contents, initial data and punctual updates are announced by the Data Producer to the reference Producer Proxy by using $Producer\_Publish\_Init$ and $Producer\_Publish\_Update$, respectively. Then, the Producer Proxy announces to the BONVOYAGE Communication System the availability of a new version of the data. To this end, it uses the $Netw\_Announce$ to notify the IRN node for the data update (see Section III-D for more details).

The Data Consumer can request a given travel-centric content or make a subscription request by using $Consumer\_Request$ or $Consumer\_Subscribe$, respectively. Both of these APIs, receive in input the list of names associated to the contents of interest for the Data Consumer. When the Data Consumer calls $Consumer\_Request$, the Consumer Proxy retrieves the initial data related to the requested names, using $Netw\_Request$. This operation is performed in a synchronous way through the request-response schema.

When the Data Consumer calls $Consumer\_Subscribe$, instead, the Consumer Proxy executes more complex tasks. First, it retrieves the initial content for the list of received names, as in the above case. Then, to reduce traffic load in the core network, the subscription requests are aggregated by name. Indeed, the Consumer Proxy maintains a list of subscribed users for each name. If at least one subscription was already issued for a given content, the new Data Consumer is added as a new entry in the list. Otherwise, the Consumer Proxy makes a subscription request using $Netw\_Subscribe$, which requires again an interaction with the IRN logical node. The subscription request is deleted when the Data Consumer closes the WebSocket connection with the Consumer Proxy.

D. Networking APIs

Logical nodes involved in Internames, that are Consumer Proxy, Producer Proxy, Named Router, NRS and IRN, are deployed within an heterogeneous network architecture. Therefore, the BONVOYAGE Communication System aims at easing their interaction during the provisioning of both request-response and publish-subscribe communication schema, as well as making the implementation of high-level functionalities independent from the underlying communication technology. To this end, *networking APIs* are exposed by a distributed middleware, as presented in its preliminary formulation in [19]. These APIs are: $Netw\_Request$, $Netw\_Subscribe$, $Netw\_Del\_Subscribe$, $Netw\_Announce$, $Netw\_Del\_Announce$, $Netw\_Notify$. Specifically, each operation triggers the execution of one or more atomic networking operations, whose implementation depends on the underlying communication technology.

$Netw\_Request$ is used to retrieve a travel-centric content. In the case the requesting node (i.e., the Consumer Proxy or any Named Router entity in Internames) is directly connected to the realm specified in the name of the content, the considered data is fetched directly from the network. Otherwise, the NRS node is contacted for driving the inter-realm routing of the request. With $Netw\_Subscribe$, the Consumer Proxy sends subscription requests to the reference IRN entity of Internames. Such a request can be canceled by using $Netw\_Del\_Subscribe$. The Producer Proxy announces the availability of new content to the IRN entity of Internames by using $Netw\_Announce$. $Netw\_Del\_Announce$, instead, is used to declare that the content is no longer available in the system. Finally, when IRN is notified about the availability of a new version of a travel-centric content, it sends a notification to all the subscribers (i.e., the Consumer Proxy) by using $Netw\_Notify$. Then, subscribers (i.e., Data Consumers) may retrieve the content by means of the *front-end APIs*.

E. Processing of DATEX II data

The proposed approach addresses real information providers serving both public and private transportation systems. To this aim, real data are managed and organized. In particular, thanks to the naming scheme, it is assumed to divide the entire Norway in tiles of $100km^2$ each. For every tile, 4 different travel-centric contents are identified, which refer to the different XML files exposed by the NPRA web server. This brings to an overall dataset with 43600 content names. Functionally speaking, original DATEX II files are processed by the Data Producer as described in Figure 3. First of all, data are fetched from the NPRA server via https, every 3 minutes (step 1). Downloaded XML files are parsed in order to identify geographical information associated to each record (step 2). Records belonging to the same tile are grouped within a single travel-centric content (step 3). Afterwards, a new XML file, formatted according to the DATEX II standard, is created for each tile (step 4). The outcomes represents the initial data, announced with the $Producer\_Publish\_Init$ to the platform (step 5). Then contents are compared with respect to those generated at the previous cycle. If an update is found, the Data Producer announces such a content to the Producer Proxy using the $Producer\_Publish\_Update$ (step 6). Finally, the Data Producer waits for future content requests coming from subscribers (step 7). The following download is scheduled after 3 minutes.

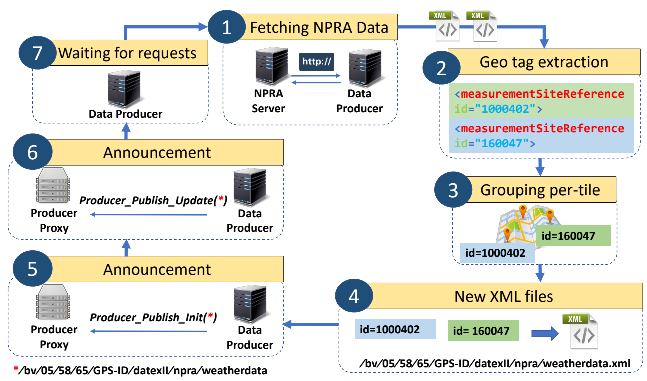


Fig. 3. Processing of DATEX II files

F. Customized caching strategies

When the content is delivered to the Data Consumer, it may be temporarily cached in intermediate Named Routers, allowing them to satisfy future requests for the same content. To this end, the BONVOYAGE Communication System integrates a customized caching strategy for DATEX II data. The leading concept is to follow a different management of cached resources, based on the type of contents they refer to (i.e., INIT or UPDATE).

The developed algorithm is summarized in the sequence diagram reported in Figure 4. It mainly embraces three possible situations. The first is verified when an INIT content is requested from the Data Consumer, but it is not available in intermediate caches. The request is forwarded by Internames to the Data Producer, that will answers with the corresponding content. Then, that content is cached in intermediate Named Routers. In order to learn about future updates for the same information, also intermediate Named Routers (like the Producer Proxy) issue a subscription request to IRN. The second case is verified when INIT or UPDATE contents are requested by the Consumer Proxy and a match is found in an intermediate cache. Now, the router simply reads the content from the cache and sends it back to the Consumer Proxy. The third possibility is verified when the Data Producer announces the availability of an UPDATE content. Here, the router is notified (as other subscribers) and INIT and UPDATE contents stored in the cache are deleted because they became obsolete. Thus, when a new request arrives, it is forwarded to the remote Data Producer. Once a new data is received, the router caches again the content and sends it backwards to the subscriber.

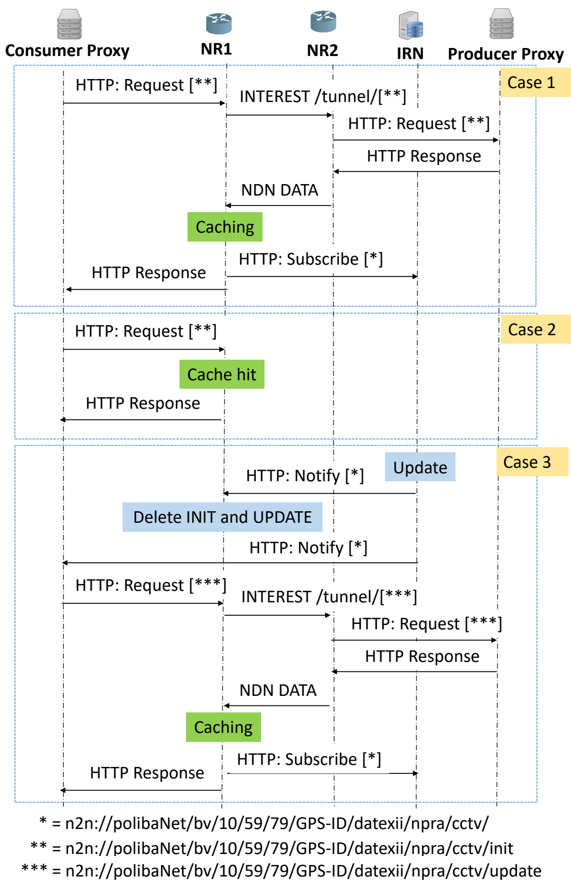


Fig. 4. Caching strategies for DATEX II contents

IV. Performance Evaluation

A preliminary performance assessment of the BONVOYAGE Communication System is discussed herein. Specifically, tests are conducted by using the experimental testbed developed in the context of the BONVOYAGE project.

At the beginning, the performance gain offered by the BONVOYAGE Communication System with respect to the baseline usage of data exposed by the NPRA server is evaluated. To this end, it is assumed that a Data Consumer is interested to retrieve contents available in a geographical area that includes Oslo city. The GPS coordinates for the low-left and high-right points of that area are: (latitude = 6, longitude = 58) and (latitude = 12, longitude = 63), respectively. Figure 5 shows the aggregate number of contents (e.g., portion of the XML file associated to a given tile) downloaded by the Data Consumer as a function of time. Results clearly demonstrate that the BONVOYAGE Communication System is able to significantly reduce the amount of data processed by the Data Consumer. In fact, it delivers only the updated portions of the original XML files that are of interest for the Data Consumer. This also leads to a significant reduction of the average bandwidth consumption at the Data Consumer side. The experimental test demonstrates that a Data Consumer directly connected to the NPRA server consumes an average bandwidth equal to 424.93 kbps. On the contrary, when the Data Consumer is attached to the BONVOYAGE Communication System, an average bandwidth consumption of 19.96 kbps is just required. Therefore, a performance gain of an order of magnitude is reached. The impact

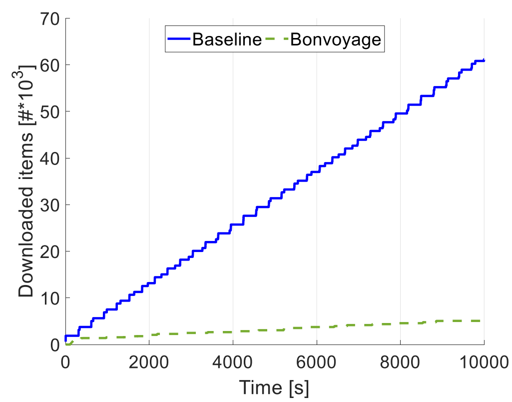
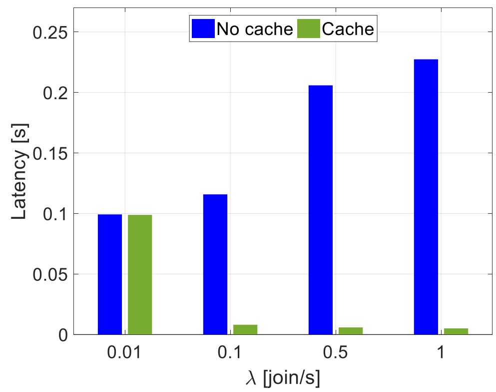


Fig. 5. Number of downloaded DATEX II records as a function of time

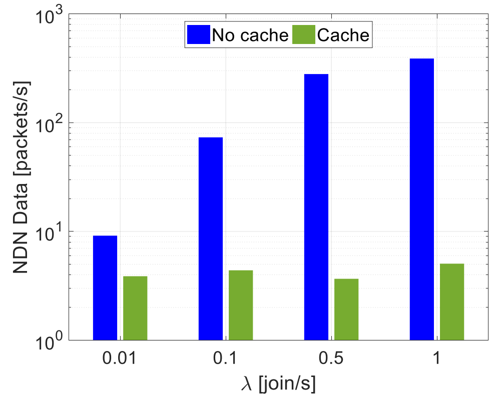
that number of Data Consumers and caching strategy have on the performance of the BONVOYAGE Communication System is evaluated too. In this case, the conducted test considers a number of Data Consumers that join the BONVOYAGE platform according to a Poisson Distribution with parameter $\lambda \in [0.01, 1]$ and ask for the same set of contents. The whole system is observed for 300 s and reported results are averaged among 15 different runs. Figure 6(a) shows the measured communication latencies. As expected, the higher the network load, the higher the communication latencies. However, the most important result is that the caching strategy guarantees a significant reduction of latencies, thus ensuring the best Quality of Service level offered to Data Consumers. Figure 6(b) reports, instead, the number of packets handled in the core network. Results highlight that the amount of traffic managed by the core network increases with the number of Data Consumers attached to the system. But, also in this case, it is possible to observe that the conceived caching strategy is able to reduce the aggregated traffic load in the core network. Indeed, the joint adoption of the BONVOYAGE Communication System and the caching strategy demonstrate interesting performance compared to a baseline approach.

V. Conclusions

This work presented the BONVOYAGE Communication System, a novel ICN-based network architecture properly con-



(a)



(b)

Fig. 6. Communication latencies (a) and traffic load handled by the core network (b)

ceived for disseminating standardized travel-centric contents over heterogeneous network domains, for which the scientific contributions does not provide significant methodologies and approaches. Its key functionalities were deeply investigated for addressing the dissemination of DATEX II data exposed by a real transportation provider in ITS contexts. Furthermore, an experimental performance assessment was also conducted to demonstrate that the BONVOYAGE Communication System effectively reduces processing complexity and bandwidth consumptions with respect to baseline mechanisms, while reaching good performance (a reduction of latency equal to 80% and a reduction of bandwidth consumption equal to 60%). To prove its suitability for large scale scenarios, future activities will consider the support for other standardized data formats, the improvement of different aspects of the whole communication system (like routing, security, and quality of service), extended performance evaluation, as well as the integration of its functionalities in complex and distributed Intelligent Transportation Systems.

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