Performance Management on Multiple Communication Paths for Portable Assisted Living

Fernando Nakayama*, **Paulo Lenz***, **Antonin LeFloch**†,
André-Luc Beylot†, **Aldri Santos***, **Michele Nogueira***
* NR2/CCSC - Federal University of Paraná, Brazil
†IRIT-INPT/ENSEEIHT - France
Emails: {fnqueiroz,pljunior,aldri,michele}@inf.ufpr.br, antonin.lefloch@etu.toulouse-inp.fr, andre-luc.beylot@enseeiht.fr

***Abstract*—Recent advances in healthcare devices and communication technologies make user remote monitoring and ubiquitous alert transmission possible. However, ensuring fast and continuous transmission of health-related data is paramount, once the information may relate to a life-threatening condition. In this context, using multiple communication paths to data transfer allows multihomed portable devices to improve network performance. But, jointly managing multiple communication paths and supporting device portability results in a challenge. This paper presents a Portable Assisted Living System (PALS) that manages performance on communication and extends the monitoring area of users in the context of Ambient Assisted Living. It relies on multipath transport-layer protocols to support multiple communication paths and to accomplish simultaneous use of paths, yielding performance and mobility gains. Emulation results show that PALS provides a bandwidth utilization efficiency of up to 87% under scenarios of high packet loss ratio.**

***Index Terms*—Ambient assited living, Portable assisted living, Multipath protocols, healthcare devices.**

I. Introduction

The aging population is growing at a fast pace. The United Nations predicts that 15.7% of the population will be 65 years old or above in 2030 [1]. This massive number of elderly people illustrate the need for remote, persistent, and reliable monitoring healthcare to offer a sustainable quality of life. Hence, the search for an active and independent user lifestyle by Ambient Assisted Living (AAL) increases. AAL reduces the dependency on personal care, integrating sensors, actuators, and communication technologies for health monitoring and the improvement of user health conditions [2].

AAL systems strongly rely on existing telecommunication infrastructures, such as cellular and fixed broadband operators and the Internet. Commonly, those operators offer no guarantees concerning data transmission for the communication paths, being susceptible to unpredicted performance variations that can affect AAL applications, such as increased packet loss rate and delay. The monitoring of vital signs and fall detection, for example, require an uninterrupted communication and low delay, since they deal with critical situations. Current AAL systems constraint user mobility, distancing from the envisaged requirements for new AAL.

Existing AALs either consider a pre-established area, where static sensors monitor the user and the environment [3], or space where mobile and wearable sensors are within the communication range of a gateway device supported for instance by cellular communication [4]. This confines the continuous user health monitoring and online healthcare to specific conditions, such as indoor or in restricted outdoor areas. Furthermore, one of the main issues for solutions using portable gateways that rely exclusively on cellular communication lies in the high cost involved, which makes the continuous use of this technology financially unfeasible in most cases [5]. Advances in healthcare devices and communication technologies endorse researchers for the envisioned ubiquitous perspective of AAL, and towards a broad range in user mobility and high bandwidth for communication.

Although several approaches have been made available to support AAL services, such as Simple Object Access Protocol (SOAP) based web services and UPnP, those methods consider only the gateway range area. Also, they are resource-demanding, leading to performance degradation in AAL environments [6]. Recent advances have focused on the deployment of Representational State Transfer (REST) web-services-based AAL [7], being less demanding and application-level portable technology. These advances allow the use of different transport-layer protocols to accomplish communication between AAL gateways and a remote web-service endpoint. However, those works ignore using multiple communication paths to improve network performance and user mobility.

This paper presents PALS, a Portable Assisted Living System that manages communication performance and extends the monitoring area for users in the context of Ambient Assisted Living systems by using multiple communication paths. It provides low delay and efficiency in bandwidth utilization by managing the communication paths in transport-layer multipath protocols. PALS extends the monitoring area for AAL users by controlling the use of different communication paths. The PALS design relies on the Multipath Quick UDP Internet Connections (MPQUIC) to handle the communication paths. MPQUIC is easily deployable, without complex modifications to the operational system of devices.

Extensive emulation results show PALS feasibility considering relevant scenarios and metrics as end-to-end delay, bandwidth utilization, and handoff time. Results compare the implementation of PALS using MPQUIC (PALS+MPQUIC) and using Multipath TCP (PALS+MPTCP), to the imple-

978-3-903176-32-4

mentations using single path protocols as TCP (PALS+TCP) and QUIC (PALS+QUIC). PALS using multipath protocols outperform PALS using single path protocols. In specific scenarios, considering global and regional values for bandwidth, latency, and data loss ratio, PALS+MPQUIC offers superior performance than PALS+MPTCP. Handover results show that PALS+MPQUIC and PALS+MPTCP handle efficiently the transition between paths from different wireless technologies.

This paper proceeds as follows. Section II presents the related works. Section III details PALS. Section IV describes evaluation and results. Section V concludes the paper.

II. Related Work

Works in the literature focus on different aspects of the AAL environment, such as improvements in data collection and activity recognition models. In most works, authors assume that data transmission happens without errors or delays, disregarding communication issues. However, performance management for communication in AAL is essential. Different traffic management strategies are available in the literature, such as over-provisioning communication links or reserve bandwidth for applications [8]. More specific solutions to improve performance are also available, such as management using software-defined networks (SDN), using alternative communication protocols, and applying fog-based solutions.

Authors in [9], used an SDN controller to control traffic flow rules to devices in AAL, avoiding congestions in the communication channel. Authors in [4] used the single path Mobile Reliable User User Datagram Protocol (MR-UDP) to improve network performance. The communication using this protocol comprised only mobile devices and the gateway. In [10] the authors proposed a fog-based approach to avoid communication bottlenecks in the cloud. The solution involved a virtual fog layer that used the cloud timely.

Previous works handling mobility and AAL relate to limited areas, usually indoor buildings. In [8], the authors have placed distributed devices in a closed environment to monitor users and communicate between themselves and with static communication gateways. In [11], it was proposed a mobile gateway for healthcare systems using 3G cellular communication. But, the integration with the static AAL environment or the handover among communication technologies were not within its scope. In [5], it was proposed a smart home where static and wearable low-power healthcare devices collect data and transfer it using a 3G/4G communication link. Although, the system achieved a successful deployment and showed good network performance, the system is limited to send only a subset of the monitored data through the 3G/4G communication link once the transmission of multiple gigabytes per day over the 3G/4G link, would dramatically increase the costs.

Few previous studies dealt with performance considering communication protocols and critical applications. In [12], they conducted experiments considering AAL applications and different transport-layer protocols, including the single path QUIC protocol. The measurement-based experiment has compared the performance of multiple transport-layer protocols taking into account as evaluation metric the loading time for different web pages. Results showed better performance from QUIC over HTTP and HTTP2, but the authors provided no information regarding applications and requirements.

In [13], the authors proposed an algorithm to provide selective redundancy for a critical application using MPQUIC and 5G wireless networks. To achieve redundancy the algorithm identifies the priority traffic and duplicates its packets through redundant paths while background traffic benefits only from single path QUIC features. Employing multiple communication technologies or the transition among the communication paths were outside the scope. One previous work tested the portability in multihomed devices when automatically transitioning among networks. In [14], the authors tested the MultiPath Transmission Control Protocol (MPTCP), that is available in a smartphone to seamlessly handoff from a WiFi to an LTE connection without user interference or losing the initial connection establishment. Despite a successful transmission ratio of 90% for MPTCP in gradual transitions between paths, MPTCP is not present in most portable devices, and its deployment requires complex software changes.

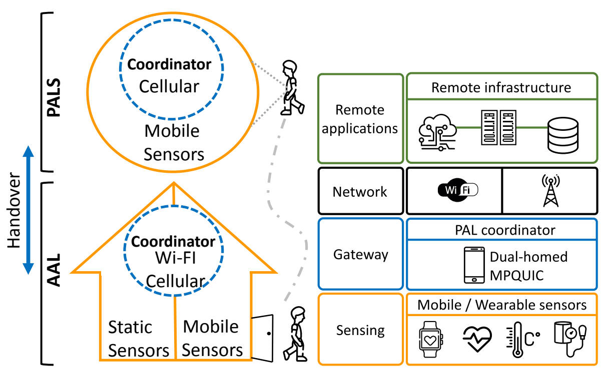
The work available in the literature regarding AAL mostly employ exclusive communication technology, even when they use multipath protocols. The use of fixed communication technologies limits the monitoring area for users while employing exclusively cellular communication brings additional expense to a system that aims at reducing costs. Even though mobility is dealt with in previous works the main approaches consider classical AAL with limited areas. Transport-layer multipath protocols adoption is gradually increasing but it still focuses on the communication between high-end hosts and servers which makes mobility complex. We advocate that the involvement of AAL systems must provide communication performance and mobility. Hence, the proposal presented in this paper advances this research direction, taking into account the AAL characteristics and requirements.

III. Portable Assisted Living System

This section describes the Portable Assisted Living system (PALS), a multi-layered system. The main functionality of the system is to provide portable assisted living using multiple communication paths and a multi-homed enabled coordinator to transfer data to a remote server. Once mobility is an inherent human behavior, users can be out of the defined AAL sensing area at a particular time. PALS allows a user to take advantage of existing AAL environments, based on static sensors and extends the AAL services to remote locations using applications that collect data from mobile sensors like those found in wearable devices.

Services, such as the continuous monitoring of vital signs and alert provision, remain invariable. The PAL system allows the simultaneous use of paths from multiple communication technologies, such as Wi-Fi and cellular, and it provides seamless transitioning among these paths without user intervention. Fig. 1a illustrates the integration between a traditional AAL and the PAL system. While the user is inside the AAL range, s/he benefits from static and mobile sensors and the coordinator device can use simultaneously the different paths provided by wireless communication technologies, such as WiFi and cellular. Once the user moves away from the AAL environment, the portable coordinator continues to monitor the mobile sensors attached to the wearable devices.

The PAL coordinator keeps sending data to a remote infrastructure by means of the cellular long range communication. The PAL coordinator assists in handover among the paths provided by wireless technologies when the user is transitioning between the AAL and PAL systems. Fig. 1b illustrates the PAL system proposed architecture which consists of four layers: sensing, gateway, network, and remote applications. This architecture encompasses different trending technologies considering the end-to-end communication cycle. For this work, we focus on the communication performance and handover functionalities that occur in the gateway layer. The next paragraphs describe in detail the gateway layer (main focus of this work) and we briefly overview the sensing layer that is responsible for collecting user data.



(a) AAL and PALS integration (b) PALS architecture

Fig. 1: PALS integration with AAL and architecture

The sensing layer consists of wearable devices collecting user information such as heart rate variation, body temperature, and blood pressure relevant for healthcare practitioners. Continuous and efficient monitoring of vital signs is a fundamental feature of the system as the collected data serves as a basis for identifying anomalies that may indicate critical condition or disorder (e.g., arrhythmia, fever, high blood pressure). Additional sensors, such as accelerometers, gyroscopes, and compasses, provide relevant data to improve user quality of life. Data from these sensors allows identifying the type and quality of the physical activity, the risk of a potential fall, and other health-related information. Sensors are distributed through different devices or combined in a single device such as a smartwatch. Each sensor provides a different type and amount of data depending on the sensor characteristics and sensing frequency.

A personal mobile device, like a smartphone, is the natural choice for playing a portable gateway role because it provides mobility, communication, and higher computing power than sensors. In PALS, this personal mobile device plays the role of coordinator, with three specific functionalities: (i) processing data from the sensing layer, (ii) data transmission using the available communication paths, (iii) assistance to the handover of the available communication paths when a user moves away or get closer to the AAL environment. In the next subsections, we describe each of the specific functionalities in detail.

1) Processing Data from Sensing Layer: Each health-related device produces a different type of data depending on the sensor attached to it. The most common vital signs are pulse, temperature, blood pressure, and respiratory rate. Each of these signs provides values that represent the status of a vital function. The coordinator processes the data from each wearable device to identify the values outside a pre-established threshold since it may indicate the presence of a critical medical condition or disorder. The establishment of the threshold includes different factors, such as the identification of sudden variation in the values of the collected signs and also static values supported by medical literature. The deployment of multiple thresholds allows the PAL coordinator to generate alerts with different levels (e.g., low risk, high risk) for several system participants, such as the user himself for low-risk alerts and emergency contacts for high-risk alerts.

2) Data Transmission Using Available Communication Technologies: In order to achieve higher performance and availability in data transmission, the PAL coordinator relies on multipath protocols. We design PALS standalone of a specific multipath protocol, but, particularly for this work, we advocate for the MPQUIC protocol. The MPQUIC protocol is a connection-oriented protocol [15] implemented on top of the User Datagram Protocol (UDP) and circumvents deployment issues as experienced by recent multipath transport-layer protocols like the Multipath TCP and Stream Control Transmission Protocol (SCTP). The implementation of MPQUIC extensions occurs in user space without complex changes to the operational system level.

The main characteristics of the MPQUIC protocol include a fast and secure connection establishment and reliable data transmission. The connection establishment occurs through a secure handshake in which the hosts negotiate the protocol version, the number and identification of paths, and the cryptography material (e.g., configuration, certificates, tokens). Both data and almost all headers are encrypted which prevents middleboxes from interfering with the communication. The information from the initial handshake serves for fast connection establishment with zero Round Trip delay Time (RTT) latency. MPQUIC uses a connection ID to enable migrations between IP-address/Port tuples. The MPQUIC frame is path specific having a field in the header representing the path ID. The acknowledgment (ACK) frame benefits from this change and it is possible to send a MPQUIC packet through one path and receive the ACK on another path. Additionally, if a stream frame is sent through one path and lost, the lost frames can be retransmitted through another path.

MPQUIC includes a path manager function to handle statistics about loss ratio and RTT as these are adjustment parameters. The congestion control algorithm in MPQUIC maintains fairness, considering the available paths. The basic principle is to make the multipath connections less aggressive to avoid performance degradation of concurrent single path connection when they share the same bottleneck. The congestion algorithm in MPQUIC is the Opportunistic Linked-Increases Congestion Control Algorithm (OLIA), which controls window size based on optimal resource use and also the responsiveness to packet loss.

3) Assistance to Handover between Available Communication Paths: Assuming that the PALS coordinator is at least a dual-homed device, it associates with different networks, such as cellular and WiFi, simultaneously. The coordinator is also a MPQUIC enabled device, meaning it can use both communication paths provided by the networks at the same time or to switch the paths from one wireless network to another without user intervention. When both paths are available, the MPQUIC protocol optimizes the bandwidth usage by using both paths to send and receive data. The path migration occurs when one of the paths becomes unavailable to the PAL coordinator. This happens when the user moves out of the communication range for one technology or when one path becomes unavailable during transmission. In either case, the PAL coordinator provides fluid transition among paths.

IV. Performance Evaluation

This section details the performance evaluation of PALS regarding two sets of experiments on the mininet emulation platform [16]. The performance evaluation comprises PALS implementations using single path protocols TCP (PALS+TCP) and QUIC (PALS+QUIC), and multipath protocols MPTCP (PALS+MPTCP) and MPQUIC (PALS+MPQUIC). The first set of experiments evaluates PALS covering a wide range of parameters, which fit the requirements of healthcare applications. This approach enables a comprehensive evaluation of PALS performance using multiple and single communication paths, rather than an evaluation considering a few well-chosen cases. The handover evaluation comprises the multipath implementations and evaluates PALS efficiency in transferring data when one communication path becomes unavailable. The characterization of the second set of experiments relies on real-world information such as data-link speed, packet loss ratio, and delay regarding a fixed and a cellular communication path. This allows us to evaluate the performance of PALS acknowledging the communication channels available in different regions worldwide.

We have conducted the experiments using Ubuntu Linux 16.04 LTS with kernel 4.4 patched with MPTCP v0.92 and running on an Intel i5-6200U @ 2.30 GHz processor. The Mininet emulation platform version is 2.2.1. The network emulation tool, responsible for inserting the link properties, queuing, propagation delay, and packet loss into the emulation, is the NetworkEmulator (Netem) [17]. The iPerf tool acts to generate additional traffic and simulate path competition [18]. Finally, the MPQUIC implementation is supported by the prototype available in [15], which relies on the Go open source programming language.

A. PALS Evaluation in Randomized Scenarios

We have defined the evaluation scenarios considering bandwidth, delays, and random packet loss for a specific workload. The values for the parameters fit the requirements of healthcare applications as observed in [19]. The parameters and workload are listed in Table I.

Experimental parameters		
Factor	Minimum	Maximum
Capacity [Mbps]	0.1	5
End-to-end Latency [ms]	0	250
No Loss [%]	0	0
Random Losses Ratio [%]	1	5
Workload [MB]	20	20

TABLE I: Experimental parameters

The emulated scenarios follow a multipath network with two multihomed enabled devices over disjoint paths, as shown in Fig. 2. The performance of the evaluated protocols indicates the variation of the parameter levels since each emulation is static. The handover evaluations follow the same scenarios with one of the paths being disabled during the experiment. Disabling one of the paths represents the user mobility when that user is drifting away from a wireless communication device, such as an access point, for instance.

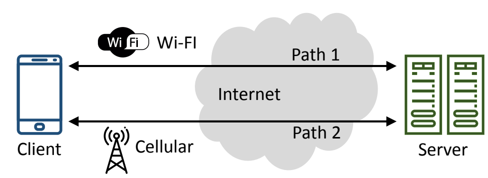


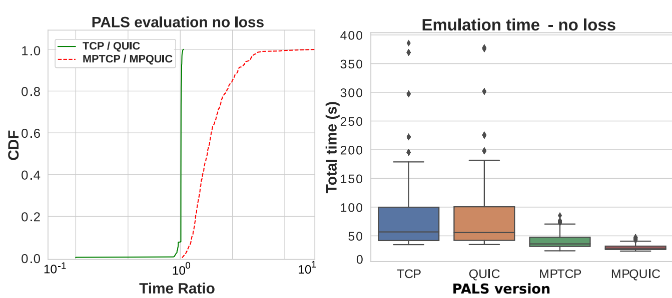
Fig. 2: Measurement Setup

The primary desired characteristics in PALS are performance and mobility. We have designed experiments to evaluate those attributes considering a wide range of possible scenarios. Because of the multi-factor aspects of the scenario and the multi-leveled factors, we have followed a fractional factorial design approach. Using the parameters available in Table I, we have created three distinct experiments to evaluate PALS: PALS performance evaluation under no loss, PALS performance evaluation under random losses, and PALS handover evaluation. For each experiment, we have assembled 50 scenarios with random values within the range from the experimental parameters. For each scenario and implementation (PALS+TCP, PALS+QUIC, PALS+MPTCP and PALS+MPQUIC), the emulation repeats for 10 times, resulting in 500 emulations per implementation. The performance experiments considering loss and no loss have a total of 2000 emulations each, and the handover evaluation has a total of 1000 emulations since it comprises only the multipath protocols. For the single path protocols the standard congestion control is CUBIC, and since there is no multipath version of this algorithm the congestion control employed in multipath tests is the OLIA congestion control algorithm.

Since fixed and cellular Internet offers different connection characteristics. We have chosen to explore the multiple scenarios provided by those different configurations. At a given time, the available links can be affected by different levels of end-to-end delay and random losses. Our experiments comprise the addition of random losses in order to evaluate PALS in demanding scenarios. For the handover evaluation, we have considered the success rate in completing the handover process and the efficiency in transferring a file through a high loss and low capacity link when one of the paths becomes unavailable. We have also evaluated the packet delivery ratio in the handover experiment, analyzing the retransmissions values for multipath protocols.

The workload is static and consists of a 20 MB file transferred from a client to a server while we measure the end-to-end delay. We have chosen this specific workload since previous evaluations with short files were conducted pointing out minor advantages in using the MPQUIC protocol [20]. The transmission of short files comprises only a small fraction of traffic types in AAL and PALS. Although multipath protocols are not designed for short file transfers [15], one of the advantages of the QUIC protocol is the single round-time-trip handshake compared to the three times round-trip-times of the TCP protocol. Thus, for small files transfers the QUIC protocol benefits from fewer connection establishments which may benefit the PALS coordinator.

*1) **PALS evaluation no loss**:* The experiment illustrates a situation where the user is inside the AAL communication range and has simultaneous access to different wireless technologies. In this experiment, we have inserted no random losses into the emulations. Our first evaluation metric is the ratio between the delay to receive the 20 MB file using the TCP protocol divided by the delay to receive the file using the QUIC protocol. For a perfect equivalence of both protocols, the ratio value is 1, being that the values above 1 indicate better performance for the implementation using QUIC, and the values below 1 indicate better performance for the implementation using TCP.



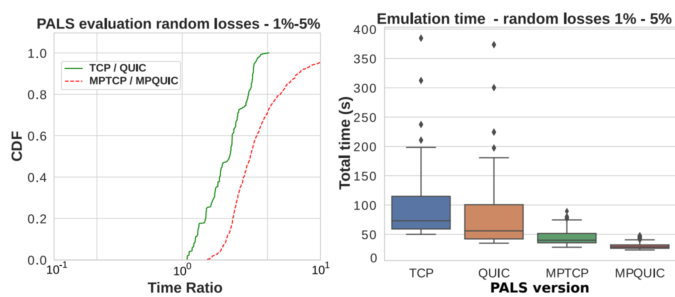
(a) Protocols evaluation - no loss

(b) Emulations time - no loss

Fig. 3: Comparison of PALS implementations under no loss scenarios

The results for PALS+TCP and PALS+QUIC are very similar over the course of all emulations results, although, in 91% of the cases, PALS+QUIC was slightly faster than PALS+TCP. This behavior is expected for single path protocols since congestion control becomes a decisive factor, and both protocols use the same algorithm. For the multipath protocols, PALS+MPQUIC has performed better in all emulations results. The packet loss for PALS+MPTCP is higher than PALS+MPQUIC. The probable cause is the more precise latency estimation of the MPQUIC protocol that contributes to finding the fastest path. The implementations using multipath protocols show better performance than PALS using single path protocols. Fig. 3b shows the boxplots for emulation times over the 500 scenarios for each PALS version. Considering all results, PALS+MPQUIC was 31.4% faster than PALS+MPTCP. Table II shows how efficiently each PALS version uses the available bandwidth. We have defined bandwidth efficiency as the ratio between goodput and the available bandwidth, regarding the values for each scenario. For the multipath protocols, we have considered the available bandwidth as the sum of the paths capacities. Results show that PALS using single path protocols and PALS+MPTCP have a similar utilization of the available bandwidth. PALS+MPQUIC showed better efficiency than the other protocols, using 88.64% of the available bandwidth.

*2) **PALS evaluation with random losses**:* This experiment depicts the same situation from the first one except for the insertion of random losses within a range of 1% to 5% packet loss ratio. Adding random losses to the emulations provides a realistic scenario since wireless communication technologies are prone to random packet loss. Fig. 4a shows the ratio between the delay to transfer the workload using PALS+TCP/PALS+QUIC and PALS+MPTCP/PALS+MPQUIC. The UDP-based versions of PALS show a clear advantage when under low bandwidth and lossy scenarios.



(a) Protocols evaluation - random losses

(b) Emulations time - random losses

Fig. 4: Comparison of PALS implementations under random losses

PALS+QUIC is more efficient than PALS+TCP in all emulations. For the implementations using multipath protocols, PALS+MPQUIC performs better than PALS+MPTCP in all scenarios. Fig. 4b shows the boxplots for all implementations considering the emulation times. The results for single path implementation show disperse values as they cannot benefit from the available paths. PALS+QUIC performs better than PALS+TCP. PALS+MPQUIC has dealt better than PALS+MPTCP with the inserted random losses with a 0.29% decrease in performance while PALS+MPTCP has shown 9.54% difference from the previous experiment. PALS+MPQUIC has also presented a lower retransmission rate than PALS+MPTCP. Table II shows the results for emulations with random losses. In [14], the authors conducted a simulation-based experiment considering the same protocols and variations in the experimental parameters. However, they considered data links with higher capacity (up to 100Mbs) than the ones we have applied in our experiment since we have adjusted our parameters considering the requirements of healthcare applications. The experimental results diverge explicitly for the scenarios with random losses, due to mainly the demanding characteristics in our scenarios.

Bandwidth efficiency no loss				
Version	PALS+TCP	PALS+QUIC	PALS+MPTCP	PALS+MPQUIC
Goodput	1.82 Mb/s	1.91 Mb/s	3.81 Mb/s	5.23 Mb/s
Bandwidth	2.90 Mb/s	2.90 Mb/s	5.90 Mb/s	5.90 Mb/s
Efficiency	62.76%	65.86%	64.58%	88.64%
Bandwidth efficiency random losses - 1% - 5%				
Version	PALS+TCP	PALS+QUIC	PALS+MPTCP	PALS+MPQUIC
Goodput	1.60 Mb/s	1.88 Mb/s	3.59 Mb/s	5.19 Mb/s
Bandwidth	2.94 Mb/s	2.94 Mb/s	5.90 Mb/s	5.90 Mb/s
Efficiency	54.42%	64.22%	60.86%	87.37%
Handover bandwidth efficiency random losses - 1% - 5%				
Version	PALS+TCP	PALS+QUIC	PALS+MPTCP	PALS+MPQUIC
Goodput	–	–	2.27 Mb/s	2.33 Mb/s
Bandwidth	–	–	3.5 Mb/s	3.5 Mb/s
Efficiency	–	–	64.91%	66.66%

TABLE II: Bandwidth efficiency

*3) **PALS handover evaluation**:* The handover among paths is one of the main reasons to follow multipath protocols in PALS. For the handover evaluation, we have considered the same experimental design used in the performance evaluation with random losses added through all emulations. For each experiment, we have disabled one of the communications interface automatically 15 seconds after the beginning of the emulations. Fig. 5 illustrates an example of a path handover.

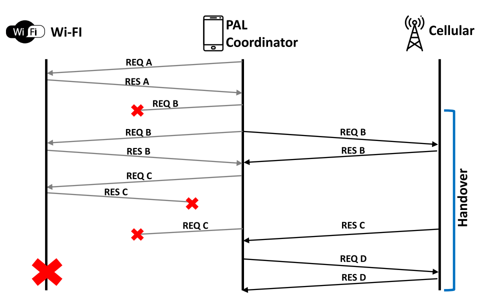
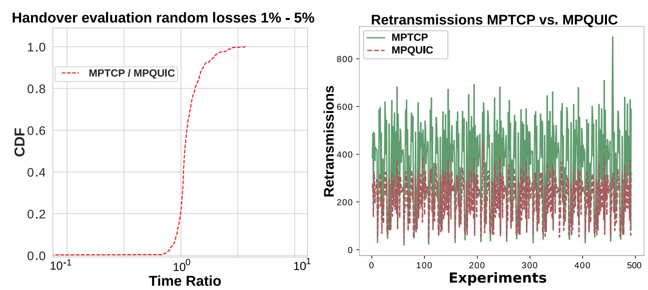


Fig. 5: Example of a possible path handover

As the PAL coordinator has access to both paths, it benefits from both communication technologies, simultaneously, even in the presence of losses. As the PAL coordinator moves away from the Wi-Fi access point, the transport-layer protocol shifts the connection to the path provided by cellular technology. For this experiment, we have evaluated retransmissions for each protocol once a high number of retransmissions may indicate the attempt to use the disabled path by the PAL coordinator.

PALS+MPTCP and PALS+MPQUIC have completed the emulations in 98.6% of the scenarios. Failures have occurred mostly when both paths presented low capacity and high end-to-end latency. Fig. 6a shows the ratio between the delay to transfer the workload with PALS+MPTCP divided by the time required by PALS+MPQUIC considering handover scenarios with losses. PALS+MPQUIC outperforms PALS+MPTCP in 78.6% of the experiments, although the time to complete the emulations was similar in most cases. Results were also comparable to the performance of the PALS implementation using single path protocols. This is expected because despite the emulations start with redundant paths, the multipath protocols benefit from them only for 14% of total time, in average. As observed in Fig. 6b, PALS+MPQUIC needs fewer retransmissions than PALS+MPTCP. This is particularly important to spare the restrained resources of the PALS coordinator considering processing power and energy. Finally, PALS+MPQUIC has obtained 66.1% of bandwidth efficiency. Both implementations offer handover capabilities and are similar in performance, enabling the deployment in a portable coordinator. Results for performance and uncomplicated deployment make MPQUIC the most suitable candidate for implementation. Our experimental results are in agreement with others [14], where the authors have also tested the handover considering MPTCP and MPQUIC protocols.



(a) Multipath handover evaluation (b) Handover emulations time with losses

Fig. 6: Handover evaluation

B. *Protocols Evaluation in Specific Scenarios*

The availability of communication technologies and bandwidth is different depending on the geographical location. To investigate the applicability of PALS in real-world scenarios, we have conducted additional experiments considering the average global Internet speeds and also in Europe, in the United States of America, and South America, for fixed and cellular communication links. Table III shows the global and regional values for fixed and mobile Internet speeds. This experiment relies on the 2019 reports provided by [21] with throughput tests carried out by users worldwide. *Speedtest.net* is a bandwidth and performance evaluation platform. The reports from 2019 comprise 500 million individual evaluations.

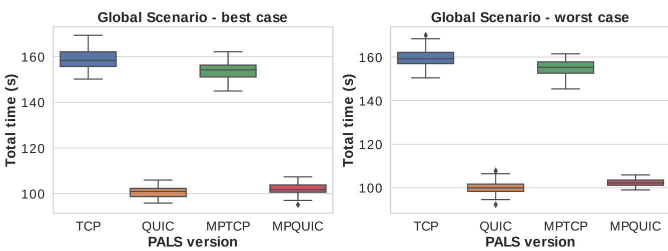
The European region comprises Germany, United Kingdom, Belgium, Spain, and France, and the South America region comprises Brazil, Peru, and Argentina. Each of the regions has provided two distinct scenarios, a best-case scenario that represents the download speeds and a worst-case scenario that depicts the upload speeds considering fixed and cellular

Global	Best-case (Download)	Worst-case (Upload)
Fixed bandwidth	76.9 Mbps	41.09 Mbps
Mobile bandwidth	33.71 Mbps	10.89 Mbps
Europe	**Best-case (Download)**	**Worst-case (Upload)**
Fixed bandwidth	50.16 Mbps	9.96 Mbps
Mobile bandwidth	26.36 Mbps	11.05 Mbps
USA	**Best-case (Download)**	**Worst-case (Upload)**
Fixed bandwidth	96.25 Mbps	32.88 Mbps
Mobile bandwidth	33.88 Mbps	9.75 Mbps
South America	**Best-case (Download)**	**Worst-case (Upload)**
Fixed bandwidth	23.64 Mbps	10.57 Mbps
Mobile bandwidth	18.50 Mbps	7.52 Mbps

TABLE III: Global and regional speeds for fixed and mobile Internet

communications. For increasing fairness to the protocols, we have included a global average of latency (24ms) and data loss ratio (5%). The evaluation of the scenarios comprises 50 repetitions for each PALS version considering the delay time to transfer a 20 MB file. The results are presented and discussed in the next sections.

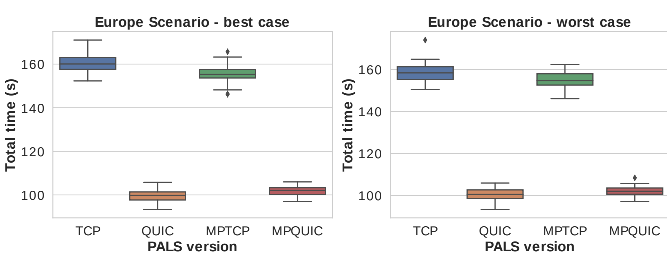
1) Global Evaluation: The UDP-based implementations PALS+QUIC and PALS+MPQUIC were faster in transferring the 20 MB file than the TCP-based versions in both scenarios. Considering the best-case scenario, PALS+QUIC and PALS+MPQUIC had similar performance while in the worst-case scenario QUIC has outperformed MPQUIC in 77% of the emulations. Fig. 7 presents the boxplots for global evaluations.



(a) Delay evaluation - best-case (b) Delay evaluation - worst-case

Fig. 7: Global evaluations

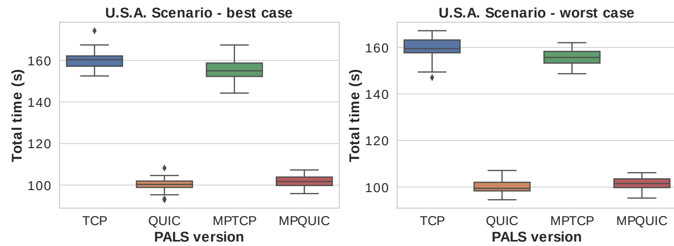
2) Europe Evaluation: Once again UDP-based implementations have outperformed TCP-based implementations. The PALS+QUIC and PALS+MPQUIC results were very close considering the number of times each protocol were the fastest through the repetitions and the total delay for each repetition. Fig. 8 presents the boxplots for Europe evaluations.



(a) Delay evaluation - best-case (b) Delay evaluation - worst-case

Fig. 8: Europe evaluations

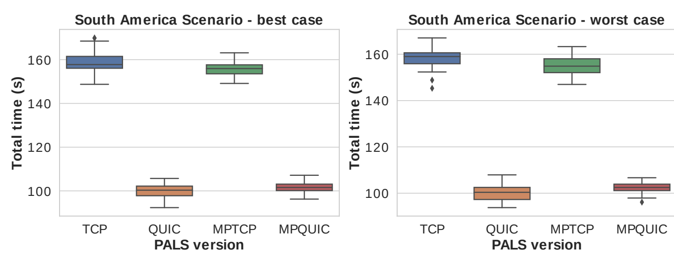
3) United States of America Evaluation: In this scenario, the PALS+MPTCP implementation has achieved the best performance considering all regional tests, approaching the performance of the PALS+TCP version. However, TCP-based versions have performed worse than UDP-based versions of PALS implementation. Considering only the UDP-based versions protocols, again the PALS+QUIC and PALS+MPQUIC implementations have performed similarly, being the PALS+QUIC protocol marginally better in most emulations. Fig. 9 presents the boxplots for the United States of America evaluations.



(a) Delay evaluation - best-case (b) Delay evaluation - worst-case

Fig. 9: United States of America evaluations

4) South America Evaluation: This scenario exhibit similar results compared to the previous evaluations, even though it presents the lowest bandwidth values considering all the regional scenarios. The PALS+TCP and PALS+MPTCP implementations performed similarly, with PALS+TCP being faster when transferring the workload. The PALS versions based on UDP were faster than those based on TCP, with PALS+QUIC being faster than PALS+MPQUIC. The worst-case scenario presented better results than the best-case scenario, showing that UDP-based PALS implementations can perform well even under adverse conditions. Fig. 10 presents the boxplots for South America evaluations.



(a) Delay evaluation - best-case (b) Delay evaluation - worst-case

Fig. 10: South America evaluations

Table IV summarizes the results for all specific scenarios experiments. The UDP-based version of PALS has shown better performance than TCP-based versions in every scenario and all repetitions. PALS+QUIC has outperformed PALS+MPQUIC in most experiments, although the average time to transfer the workload was similar. Considering only the multipath protocols, PALS+MPQUIC has sown better performance than PALS+MPTCP in these specific scenarios. The PALS+QUIC implementation has considerably outperformed PALS+MPTCP. The probable cause is the additional delay caused by the TCP handshake, and the different congestion control schemes employed in the tests.

Protocol				
Version	**PALS+TCP**	**PALS+QUIC**	**PALS+MPTCP**	**PALS+MPQUIC**
Global best	158,83	100,70	153,98	102,09
Global worst	159,71	100,25	154,86	102,39
Europe best	160,64	99,46	155,30	101,81
Europe worst	158,54	100,55	154,68	102,02
USA best	160,85	100,05	154,88	101,74
USA worst	159,56	99,83	155,79	101,52
S.A. best	159,60	100,52	155,80	102,01
S.A. worst	158,40	100,30	154,76	102,74

TABLE IV: Average delay in seconds per region

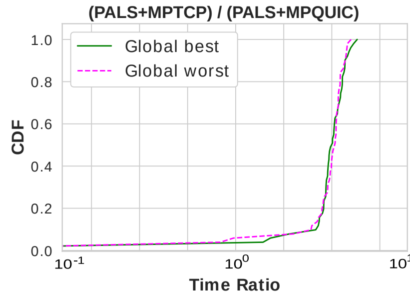


Fig. 11: Evaluation of multipath PALS versions in global scenarios

C. Discussion

Regarding both experiments and considering the scope of this work, the PALS+MPQUIC implementation meets the requirements that can handle multiple communication paths to enhance performance and assist in extending the monitoring area in assisted living systems. However, the effectiveness of employing multipath protocols should be further studied and applied in specific situations. Below, we discuss results and insights regarding the use of multipath protocols.

For the randomized scenarios, the purpose was to compare PALS versions regarding performance and mobility in a broad range of cases. The capabilities for the disjoint paths were selected at random, enabling multiple combinations of speed, delay, and packet loss rate. This allows the multipath versions of PALS to have a broader range of resources available. PALS versions implemented over single path protocols must deal with the characteristics of the exclusive path. The impacts of the path characteristics are even more apparent in scenarios of high delay and packet loss ratio. Even though the results were favorable for the multipath implementations, we have noticed that in specific situations, the performance was comparable to the single path implementations. Those situations specifically involved the scenarios with higher bandwidth available. These observations have encouraged us to develop further tests considering a realistic approach. The evaluation of specific scenarios has brought a sharper interpretation of the feasibility of using multipath.

To provide the desired design characteristics, PALS must rely on a multipath protocol. However, considering exclusively the performance in the specific scenarios evaluation, the PALS+MPTCP implementation offered no notable advantages. In this case, PALS+MPTCP still benefits from using multiple communication technologies and provides smooth transitioning among those technologies, but offers no performance improvements when compared to the single path implementations or the PALS+MPQUIC implementation. Fig 11 illustrates the time ratio regarding multipath PALS implementations in global scenarios. PALS+MPQUIC shows considerably better performance in specific scenarios than PALS+MPTCP. The superior performance persists throughout all emulations and for every region evaluated.

Future solutions relying on multipath protocols must be carefully planned. They must acknowledge the resources and characteristics of the implementation environment and also evaluate the availability of the multipath protocol. For instance, MPTCP requires complex changes at the operating system level while (MP)QUIC runs in user-space, being easily deployed. Additionally, topics that were not within the scope of this work must be examined, such as the security aspects of multipath protocols, the consequences of the additional overhead because of multiplexing, and improvements on congestion control considering those protocols.

V. Conclusion

The forthcoming AAL systems must properly benefit from the advances in technology to provide improvements in communication and deliver ubiquitous monitoring for users. In this paper, we introduced a portable assisted living system (PALS) to enhance communication performance and extend the AAL health monitoring services to remote locations. The PAL coordinator relies on the transport-layer Multipath QUIC protocol to use multiple communication paths simultaneously and to promote seamless handover between paths. We evaluated PALS by emulation, and we compared the results from its implementation using TCP and QUIC, as single path protocols, and MPTCP and MPQUIC, as multipath protocols. Emulation results in randomized scenarios showed that the implementation of PALS using MPQUIC provides a faster transmission rate and higher bandwidth efficiency than using single path protocols and the multipath MPTCP protocol. PALS efficiently handles the transition between paths from different communication technologies. Emulation results in scenarios built from real-world data showed that the PALS implementation using MPQUIC is the best alternative considering the multipath protocols. PALS implementation presented good performance under lossy scenarios, making it a practical solution bearing in mind the environment provided by the existing communication technologies, such as cellular and fixed broadband, and also the Internet. This work is the first step to the deployment of a portable assisted living system. As an upcoming work, we envision the implementation of a novel congestion control scheme for multipath protocols that allows traffic prioritization for mixed-criticality applications.

Acknowledgment

We would like to acknowledge the support of the Brazilian research agencies: CAPES, grant #88882.382204/2019-01; RNP, grant #99/2017; and CNPq, grant #309129/2017-6, #309238/2017-0, #436649/2018-7 and #426701/2018-6.

REFERENCES

[1] W. H. Organization, “World report on ageing and health,” World Health Organization, Tech. Rep., 2015, Accessed: Jul/2020.

[2] P. Rashidi and A. Mihailidis, “A survey on ambient-assisted living tools for older adults,” *IEEE journal of biomedical and health informatics*, vol. 17, no. 3, pp. 579–590, 2012.

[3] R. I. Goleva, N. M. Garcia, C. X. Mavromoustakis, C. Dobre, G. Mastorakis, R. Stainov, I. Chorbev, and V. Trajkovik, “Aal and ele platform architecture,” in *Ambient assisted living and enhanced living environments*. Elsevier, 2017, pp. 171–209.

[4] B. Gomes, L. Muniz, F. J. d. S. e Silva, L. E. T. Ríos, and M. Endler, “A comprehensive cloud-based iot software infrastructure for ambient assisted living,” in *International Conference on Cloud Technologies and Applications (CloudTech)*. IEEE, 2015, pp. 1–8.

[5] A. Elsts, X. Fafoutis, P. Woznowski, E. Tonkin, G. Oikonomou, R. Piechocki, and I. Craddock, “Enabling healthcare in smart homes: The sphere iot network infrastructure,” *IEEE Communications Magazine*, vol. 56, no. 12, pp. 164–170, 2018.

[6] J. Parra, M. A. Hossain, A. Uribarren, and E. Jacob, “Restful discovery and eventing for service provisioning in assisted living environments,” *Sensors*, vol. 14, no. 5, pp. 9227–9246, 2014.

[7] M. A. Hossain, J. Parra, S. M. M. Rahman, A. Alamri, S. Ullah, and H. T. Mouftah, “From sensing to alerting: A pathway of restful messaging in ambient assisted living,” *IEEE Wireless Communications*, vol. 23, no. 2, pp. 102–110, 2016.

[8] T. Zinner, F. Wamser, H. Leopold, C. Dobre, C. X. Mavromoustakis, and N. M. Garcia, “Matching requirements for ambient assisted living and enhanced living environments with networking technologies,” in *Ambient assisted living and enhanced living environments*. Elsevier, 2017, pp. 91–121.

[9] D. P. Isravel, S. Silas, and E. B. Rajsingh, “Sdn-based traffic management for personalized ambient assisted living healthcare system,” in *Intelligence in Big Data Technologies—Beyond the Hype*. Springer, 2020, pp. 379–388.

[10] Y. Nikoloudakis, S. Panagiotakis, E. Markakis, E. Pallis, G. Mastorakis, C. X. Mavromoustakis, and C. Dobre, “A fog-based emergency system for smart enhanced living environments,” *IEEE Cloud Computing*, vol. 3, no. 6, pp. 54–62, 2016.

[11] T. H. Laine, C. Lee, and H. Suk, “Mobile gateway for ubiquitous health care system using zigbee and bluetooth,” in *International Conference on Innovative Mobile and Internet Services in Ubiquitous Computing (IMIS)*. IEEE, 2014, pp. 139–145.

[12] T. Zinner, S. Geissler, F. Helmschrott, S. Spinsante, and A. Braeken, “An aal-oriented measurement-based evaluation of different http-based data transport protocols,” in *Symposium on Integrated Network and Service Management (IM)*. IEEE, 2017, pp. 1162–1167.

[13] R. S. Mogensen, C. Markmoller, T. K. Madsen, T. Kolding, G. Pocovi, and M. Lauridsen, “Selective redundant mp-quic for 5g mission critical wireless applications,” in *89th Vehicular Technology Conference (VTC2019-Spring)*. IEEE, 2019, pp. 1–5.

[14] Q. De Coninck and O. Bonaventure, “Multipathtester: Comparing mptcp and mpquic in mobile environments,” in *Network Traffic Measurement and Analysis Conference (TMA)*. IEEE, 2019, pp. 221–226.

[15] ——, “Multipath quic: Design and evaluation,” in *International Conference on Emerging Networking EXperiments and Technologies*, ser. CoNEXT ’17. ACM, 2017, p. 160–166.

[16] N. Handigol, B. Heller, V. Jeyakumar, B. Lantz, and N. McKeown, “Reproducible network experiments using container-based emulation,” in *International Conference on Emerging Networking Experiments and Technologies*, 2012, pp. 253–264.

[17] S. Hemminger *et al.*, “Network emulation with netem,” in *Linux conf au*, 2005, pp. 18–23.

[18] C.-H. Hsu and U. Kremer, “Iperf: A framework for automatic construction of performance prediction models,” in *Workshop on Profile and Feedback-Directed Compilation, Paris, France*. Citeseer, 1998.

[19] G. Cisotto, E. Casarin, and S. Tomasin, “Requirements and enablers of advanced healthcare services over future cellular systems,” *IEEE Communications Magazine*, vol. 58, no. 3, pp. 76–81, 2020.

[20] T. Viernickel, A. Froemmgen, A. Rizk, B. Koldehofe, and R. Steinmetz, “Multipath quic: A deployable multipath transport protocol,” in *International Conference on Communications (ICC)*, 2018, pp. 1–7.

[21] O. SPEEDTEST, “Speedtest global index,” OOKLA, Tech. Rep., 2019, Accessed: Jul/2020. [Online]. Available: www.speedtest.net/reports/