A Mobile Quality-oriented Cooperative Multimedia Delivery Solution

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***Abstract*—Mobile video traffic is rapidly growing, putting significant pressure on current heterogeneous wireless networks. Common data is traditionally requested by multiple users from server or cache devices. This results in the same data being sent across the network multiple times causing unnecessary congestion. The proposed cooperative solution allows neighbouring devices to share content that was previously received with interested peers. In this paper, a Mobile aware Quality-oriented Cooperative Multimedia Delivery Solution is proposed which allows peer devices to identify neighbouring host devices while considering their own mobility. Simulated testing shows that the solution is capable of identifying the most suitable host while travelling at different speeds and maintaining a suitable quality level by adapting the content to meet network conditions. State-of-the-art comparative studies are outperformed by maintaining good quality with increasing speed in a mobile environment.**

***Index Terms*—DASH, cooperative P2P, video delivery, device-to-device**

I. Introduction

Mobile video traffic is expected to grow 9-fold by 2021 accounting for 79% of global mobile data traffic [1]. This rapid growth is contributing to growing issues experienced by the underlying infrastructures. Indeed the current growth of traffic is causing a bandwidth bottleneck on the Internet [2]. A potential solution to this bottleneck is the reuse of resources at the network edge in order to reduce repeated requests to remote data centres. Cooperative distribution over device-2-device (D2D) communication is an approach that facilitates the sharing of network and device resources as well as encouraging the reuse of data through local caching. Cooperation can also bring better connectivity to rural areas where there is little to no network coverage.

Centralised D2D solutions manage devices through a central point such as an Access Point (AP) or Base Station (BS). These approaches are suitable in areas with well-established infrastructure and can offload some of the pressure from the existing networks. Such a centralised approach becomes unfeasible in a rural environment due to the cost of extending the existing infrastructure. A decentralised solution allows the existing mobile entities to cooperatively distribute content with neighbouring devices without the knowledge of the overall network. The self-managing nature of a decentralised approach becomes a major challenge when mobility is introduced. Delays and interruptions can become frequent if devices do not consider the impact of geographical location and mobility due to limited radio ranges and unexpected traffic.

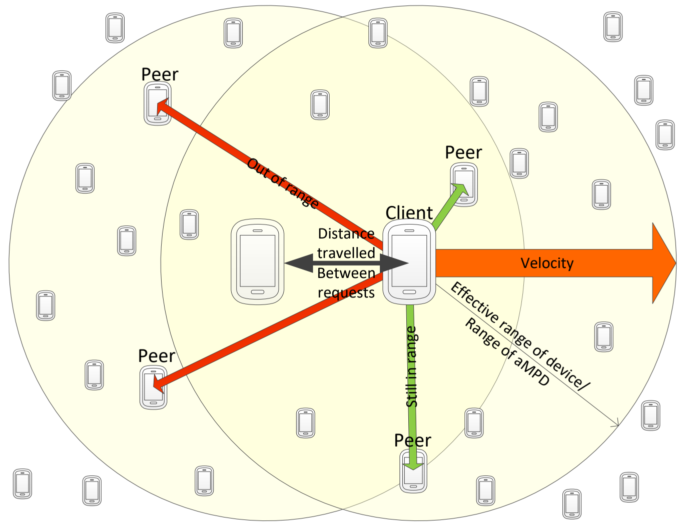

Fig. 1. Overview of application scenario

This paper proposes a novel **Mobile aware Quality-oriented Cooperative Multimedia Delivery Solution (MENCO)** to address the issues introduced by mobility in a decentralised heterogeneous environment. The impact of client mobility is illustrated in Fig. 1 where the client is shown to go out of communication range between requests, therefore potentially resulting in dropped content and/or failed requests. MENCO considers the positioning and movement of neighbouring devices in relation to the client as part of the host selection mechanism in order to avoid the risk of communication loss during content requests. The goal of MENCO is to achieve the best streaming experience by selecting the most suitable hosts and adapting the content quality to suit the network conditions.

The rest of this paper is organised as follows. Section II discusses the related works from the literature. Section III introduces MENCO's architecture and section IV present a description of the proposed solution. Simulation and results are introduced and discussed in section V. Finally, section VI includes conclusions, some final remarks and planned future work.

II. Related Works

Considerable work has been performed to enable mobile multimedia streaming in varying scenarios. Vehicular networks are a main area of focus because solutions which work at higher speeds are expected to perform well in lower speed scenarios. An early study analysed the performance of the MPEG-DASH standard [3] in a vehicular mobile environment [4]. The authors compared a prototype DASH implementation against a number of propriety systems including Apple HTTP Live Streaming [5], Adobe HTTP Dynamic Streaming [6] and Microsoft Smooth Streaming [7]. The prototype implementation was shown to improve performance in the mobile environment.

Zhu et. al. [8] proposed a mobility aware handover mechanism for VANET networks. The authors have used MPTCP to achieve high transmission rates while employing a non-cooperative game to balance the load and maintain fairness. Simulation results show a decrease in delays and an overall improvement in throughput when mobility awareness is implemented alongside MPTCP. Xu et al. [9] proposed a VoD solution for urban vehicular environments which is user-centric and aims to deliver a high Quality of Experience (QoE) to users. The authors introduce a storage scheme for distributing segments across a distributed environment, and a search scheme to reliably find and download segments via a 4G Chord overlay structure.

Collaborative multimedia streaming emerged as an approach for mobile devices to share the task of streaming multimedia content either by sharing resources or performing local caching. Lee et. al. [10] proposed a collaborative streaming service using MPEG-DASH for smart mobile devices. Short-range Bluetooth ad-hoc networks are used in order to cooperatively download common multimedia content. The solution achieves improvements of up to 50% for download speeds. Wu et. al. [11] introduced a collaborative video distribution architecture. By considering the social and mobile characteristics of the mobile devices, the authors transfer the distribution of content at the network edge to mobile devices. Results show that the load on the BS is significantly reduced while transmission resources are more efficiently utilised through cooperation.

Rovcanin [12] proposed a DASH-Based distribution system which considers the network conditions and the device characteristics. This solution dynamically updates the content MPD file based on which devices are currently holding the segments. Powerful peers such as laptops are prioritised as local hosts. A peer-assisted DASH solution is proposed and compared against a conventional DASH approach [13]. The novelty of this paper was the introduction of peer-assistance into MPEG-DASH. The authors show that the P2P traffic contributes to more than 50% of all traffic therefore drastically reducing traffic to/from the server. Gao et. al. [14] introduced a cooperative mobile video streaming solution. Mobile users can share their cellular resources to cooperatively stream video. Improvements of up to 30% bitrate and 50% social welfare are achieved.

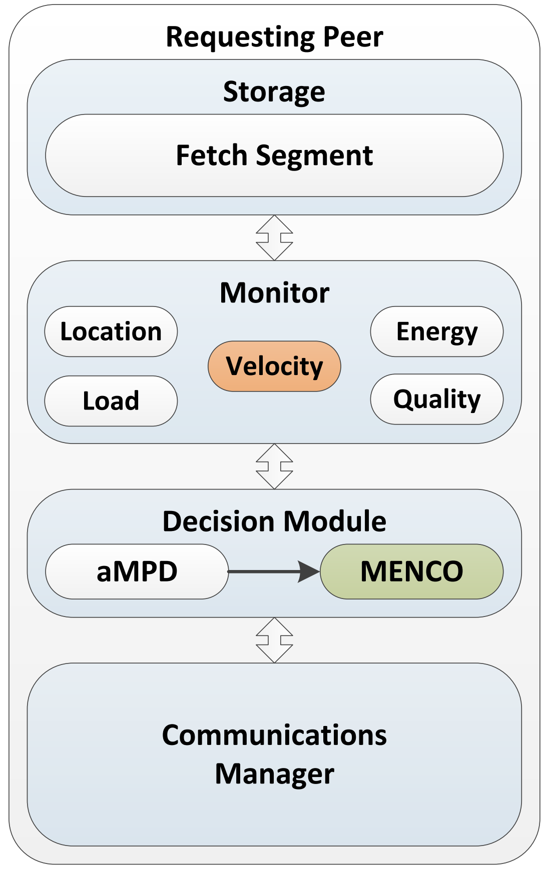

Fig. 2. Representation of Peer Structure

Centralised approaches are typically considered in the literature where peers have access to a central point with knowledge of the network, such as a base station or access point. A decentralised approach removes this reliance on infrastructure but introduces challenges for the management of the network. Zhou [15] described a novel Device-to-Device (D2D) video distribution solution. The authors consider a purely distributed approach with no central monitoring. Testing and theoretical analysis show that the solution is efficient and robust in a dynamic environment. Natali et. al. [16] proposed a P2P-DASH architecture that makes use of multiple overlays to guide peers between clusters arranged by currently requested qualities. These layers correspond to the various quality representations described by the DASH MPD. Significant testing is performed with high delivery and low delay rates achieved.

While works have considered mobile, collaborative and decentralised streaming, little consideration has been given to the idea of a collaborative purely decentralised adaptive streaming architecture. This paper describes such a solution which has the potential to extend network coverage beyond established infrastructure while alleviating some of the pressure from the network edges.

III. MENCO Architecture

This paper introduces mobility awareness to a distributed co-operative streaming solution proposed in our previous work [17]. A distributed architecture consists of various devices randomly situated with the capability to communicate directly with each other. No infrastructure is considered as part of the MENCO architecture with users responsible for discovering and maintaining relationships with neighbouring devices. This section introduces the general peer architecture assumed in this work and the file structure introduced for maintaining relationships.

A. Peer Overview

Fig. 2 provides an illustration of the peer architecture employed as part of this work. Four main components make up the structure of a peer: *Storage*, *Monitor*, *Decision Module* and *Communications Manager*. Segments that are contained on a device are stored within the *Storage* module and are fetched when necessary via a fetch method unique to the device. The *Monitor* unit observes the performance of the device by monitoring a number of individual metrics including throughput, energy consumption, location, load and velocity. These metrics are used by the algorithms to determine the best quality and host for future segment requests.

All decisions are made within the *Decision Module* which contains the various algorithms and the aMPD file. The *Decision* module is also responsible for updating the aMPD. Finally, a *Communications Manager* enables the peer device to identify and communicate with neighbouring peers regardless of the network interface used. Interface selection is not considered within this work and is considered to be IEEE 802.11, a wireless LAN standard widely used in practice. A more detailed discussion of these modules is presented in our previous work [17].

B. Area Media Presentation Description file (aMPD)

This file is responsible for keeping track of the various neighbouring devices. Each device has a unique aMPD corresponding to its location. Within this aMPD, the content is described similarly to the standardised MPD XML format presented within the MPEG-DASH standard. However, instead of each segment pointing to a unique URL, a client list of potential hosts is included. For each such host, geographical location and load information are stored. Each device is responsible for updating their local file with the relevant information. The aMPD is periodically *cleaned* to remove out of date hosts by considering a host that is a significant distance away (e.g. 50m) to be no longer viable. This not only keeps the knowledge of the device relevant, but it also reduces the decision time involved when finding a suitable host. The range of the aMPD is up to the user device, longer ranges mean the node has greater awareness but greater lookup times and vice-versa.

IV. MENCO Algorithm

MENCO extends upon the work described in [17] which involved an energy-aware adaptive multimedia streaming solution in a distributed environment. The MENCO algorithm runs once every segment duration to identify the desired segment quality and host of the next request. The quality adaptation mechanism is brought over from that work and can be seen in Fig. 3 within the MENCO module. This work focuses on extending the host peer selection mechanism from the previous work to also consider mobility, creating the Mobile Host Peer Selection (MHPS) module. A mobility metric is introduced which considers the angular distance between a host and the client's path of travel, and also the speed of the client. The distance utility is adjusted to accommodate for the uncertainty introduced by client mobility during a TCP session. Finally, the host selection algorithm is extended to allow the client to wait or perform fast requests when necessary.

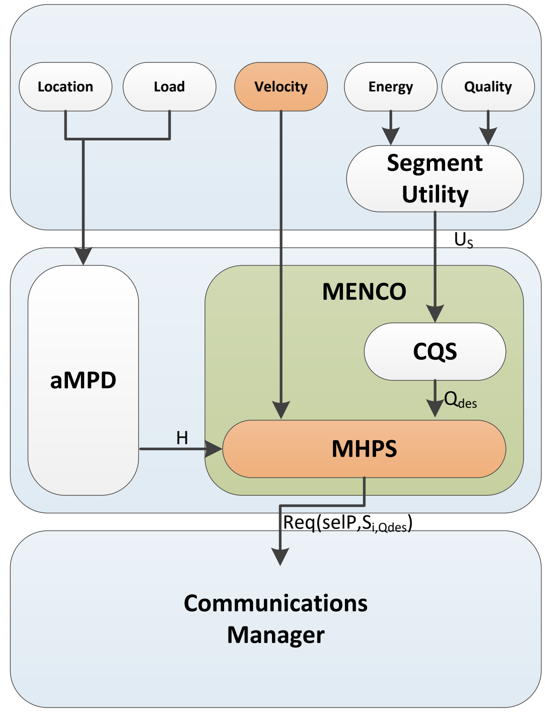

Fig. 3. MENCO Module Implementation

A. Host Utility

A host rating utility U_H was introduced in [17] which gives a rating to a host based on the distance the device is located from the client, and the average load observed on the host. eq. (1) shows the original utility function where u_L is the load utility described in the paper, u_D is the distance utility which has been further modified for this work, w_L and w_D are the load and distance weights respectively which sum to 1. A brief description of each of these utilities follows.

$$U_H = u_L^{w_L}.u_D^{w_D} \tag{1}$$

1) Distance Utility: The distance utility function is shaped based on the rate-distance adaptation profile of IEEE 802.11n. The general equation is represented in eq. (2).

$$u_D = \begin{cases} 1, & \text{for } D \leq D_{min} \\ 1 - \frac{1}{1+e^{\frac{\gamma - D}{\delta}}} & \text{for } D_{min} < D \leq D_{max} \\ 0, & \text{otherwise} \end{cases} \quad (2)$$

Here, D is the distance from the client to host, D_{min} is the distance up to which rate adaptation does not occur, D_{max} is the maximum distance above which the rates are no longer viable. γ and δ are two constants used to shape the curve based on the modelled profile. Original values considered only a static environment allowing the curve to give ratings to further distances. Based on the observed performance of TCP over varying distances, distant nodes are not as reliable in mobile scenarios as they are in a static scenario. If a device goes out of range, there is a high potential for large timeouts, drastically impacting the quality for the user. To compensate for this, the sigmoid was adjusted to reduce the reputation given to distant nodes. The shaping parameters, γ and δ, were recomputed to consider a smaller range. By considering the maximum distance to be $D_{max} = 35m$ and minimum distance $D_{min} = 5m$, updated values of $\gamma = 25$ and $\delta = 4.35$ were found.

2) Load Utility: The load utility, u_L, metric reflects the amount of data a host has shared with neighbouring devices, indicating their workload. It is used to encourage fairness in the host selection mechanism and is calculated using eq. (3).

$$u_L = \begin{cases} 1, & \text{for } Tx_{Av} \leq Tx_{min} \\ \frac{Tx_{max} - Tx_{Av}}{Tx_{max} - Tx_{min}} & \text{for } Tx_{min} < Tx_{Av} \leq Tx_{max} \\ 0, & \text{otherwise} \end{cases} \quad (3)$$

Here, Tx_{Av} is the average transmitted load (Mbps), Tx_{min} is the minimum load (Mbps) and Tx_{max} is the highest load (Mbps). Th_{min} and Th_{max} are used to calculate Tx_{min} and Tx_{max} respectively. These are the required rates to achieve the lowest quality and the highest quality level, respectively.

B. Mobility Utility

The mobility utility uses a sigmoid curve to map the angular distance and speed of the user to a utility function. The angular distance can be described as the angle between the path of travel vector, and the straight line vector from the peer to the host in question. An angular distance of 0 is ideal while an angular distance of $\geq \pm 90\deg$ or $\geq \pm\frac{\pi}{2}$ is treated as the worst case scenario. The value of ϵ is directly related to the midpoint of the linear curve which is considered to be at $\pm 45\deg$ or $\pm\frac{\pi}{4}$. X is a scaling constant for the speed and is adjusted based on the scenario. Finally, ζ is calculated by considering the point of inflection. At this point, the second derivative $u''_M = 0$ and substituting the values for $X, \epsilon, S = 0, \theta = \frac{\pi}{4}$ gives ζ. The final utility is shown in eq. (4).

$$u_M(\theta, S) = 1 - \frac{1}{1 + e^{\frac{\epsilon X - |\theta| S}{\zeta S}}} \quad (4)$$

Where u_M is the mobility utility, θ is the angle between the path of travel and the host, S is the speed of the client, ϵ, ζ, X are constants for controlling the shape of the curve. In order to normalise the output of the function, the utility is divided by the maximum u_M which is considered to be at $\theta = 0$ for any speed S.

C. Host Mobility Utility

The host utility is combined with the mobility utility to create the "Host Mobility" utility U_{HM}. The new utility acts as a multiplicative weight to the existing host utility. The mobility utility will have no influence when the user is stationary. The host mobility utility is shown in eq. (5).

$$U_{HM} = U_H.u_M \quad (5)$$

Here, U_H is the Host utility from [17] and u_M is the novel mobility utility. U_{HM} is the host mobility utility used for selecting the best host to request from.

D. MENCO Algorithm

Algorithm 1 Mobile Host Peer Selection (MHPS) Algorithm

Input: Host List $aMPD$; Quality level to request, QL;
Output: Best Host to request from, $bestHost$;

```
for all host in aMPD do
    Compute host.U_H using eq. (1)
    Compute host.u_M using eq. (4)
    Compute host.U_HM using eq. (5)
end for
Select bestHost=argmax(host.u_HM) from aMPD
if bestHost.U_HM < k_L then
    Hold QL
    Perform requestWait
else if bestHost.U_HM > k_H then
    Hold QL and bestHost
    Perform fastRequest
else
    Request from bestHost
end if
```

The proposed MENCO algorithm extends upon the Host Peer Selection (HPS) algorithm previously proposed in [17]. Two new mechanisms are introduced to the algorithm to improve the overall performance, *requestWait* and *fastRequest*.

1) "requestWait" Mechanism: Triggered when U_{HM} is below the lower threshold, k_L. This wait mechanism holds the clients current selected quality but waits until the next request period before selecting a host. When the hosts available to the peer have poor ratings according to the U_{HM}, the *requestWait* mechanism stops the peer from requesting content which will likely fail to be answered.

2) "fastRequest" Mechanism: Triggered when U_{HM} is above an upper threshold, k_H. This mechanism is introduced to offset the reduced performance introduced by the Wait. It allows the client to hold the current selected quality and host in order to rapidly request each segment as the previous is

TABLE I
SIMULATION SETTINGS

Parameter	Value
Peer Distribution	RandomBoxPositionAllocator
Peer Density	1000 Persons per sq. km.
Host Mobility Model	ConstantPositionMobilityModel
Client Mobility Model	ConstantVelocityMobilityModel
Wi-Fi Mode	IEEE 802.11n 2.4GHz Ad-hoc
Simulation Length	100s
Segment Duration	1s
Number of runs per test	5
Client Speed (km/hr)	0; 25; 50
Video Rates (Mbps)	0.12; 0.24; 0.48; 0.96; 1.92
X	15
k_L	0.1
k_H	0.9

received. This condition ends when the measured U_{HM} of the host drops below the threshold indicating that the selected host is going out of range or struggling to maintain high performance. Algorithm 1 provides a pseudo-code explanation of the host selection algorithm. The threshold values k_L and k_H were set through a trial and error approach and are presented in Table I.

V. PERFORMANCE EVALUATION

The performance of MENCO is analysed through simulation-based testing using the Network Simulator 3 (NS-3). Two comparison works are considered, DAV [12] and ENCO [17]. DAV is a DASH-based solution that adapts the video quality based on the previously measured throughputs. It selects hosts based on a gateway reputation generator which considers the features of host devices. In this work, all devices are treated equally, and no gateway is available. Instead, DAV can select its host from the local aMPD file. ENCO is a similar solution to MENCO which introduces a distributed solution for adaptive media delivery while maintaining a balance between energy and quality. ENCO does not, however, consider mobility as part of its host selection mechanism.

A. Simulation Setup

A scenario is created in NS-3 to simulate a client travelling through a congested environment while viewing a video on their mobile device. The congestion of the scenario is considered to be 1000 persons per km^2 to reflect a simple urban environment. Three speeds are considered as part of the study, $0km/hr$ or stationary, $25km/hr$ and $50km/hr$. Each test is run five times with different simulation seeds for a duration of 100s each.

As the main focus of this work is mobility aware host selection, the performance of each solution is assessed using two metrics: throughput (Mbps) and PSNR (dB). The PSNR is calculated using the quality estimation formula introduced by Lee et al. in [18] as shown in eq. (6). When using the PSNR formula, the adaptive nature of MENCO is considered

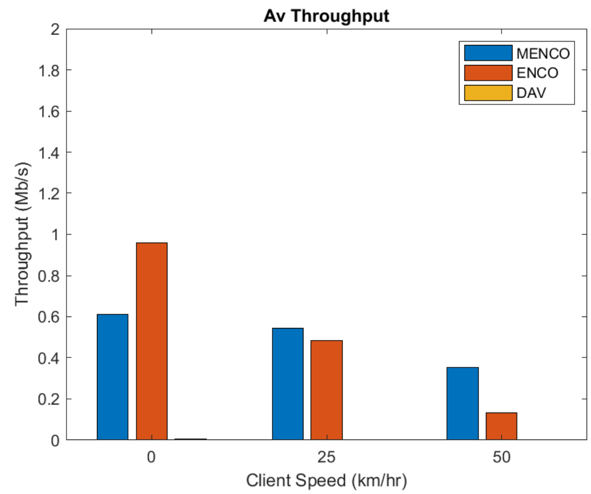

Fig. 4. Average Throughput Results

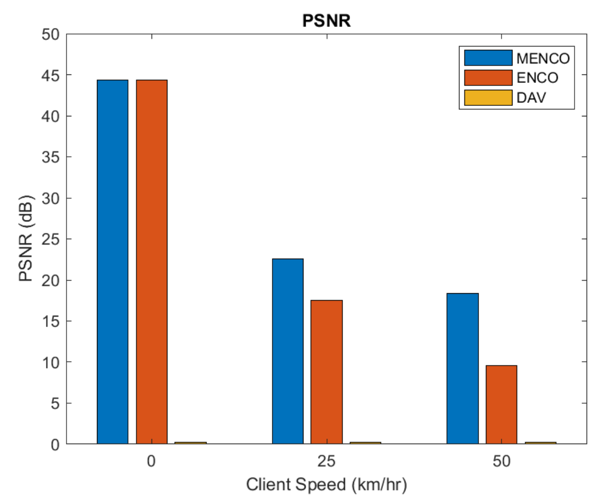

Fig. 5. Average PSNR Results

by using the expected bitrate for each segment during the loss calculation. The maximum request bitrate is considered as the max bitrate, in this case, 1.92 Mbps. Therefore, $Max_{Bitrate}$ is the maximum available segment bitrate (Mbps), $Exp_{Bitrate}$ is the requested rate for the segment (Mbps) and $Meas_{Thr}$ is the measured throughput (Mbps). The settings used in the simulation can be seen in Table I.

$$PSNR = 20 * log_{10}\left(\frac{Max_{Bitrate}}{\sqrt{(Exp_{Bitrate} - Meas_{Thr})^2}}\right) \quad (6)$$

B. Results and Analysis

In Fig. (4), the average throughput for each scenario is shown. Considering the stationary scenario, it is clear that ENCO is outperforming the proposed solution. This is due to the modified distance utility and the Wait mechanism.

ENCO will always send a request once a host is found, while MENCO will only send a request when the host is strong enough. This can lead to situations were ENCO can more freely request data than MENCO. However, once mobility is introduced, ENCO suffers from this. Further devices now become quickly unreachable leading to large timeout delays in the TCP stream. Meanwhile, MENCO only commits to a host if its performance and location are suitable, as described in Algorithm 1. MENCO marginally outperforms ENCO in the $25km/hr$ scenario but almost triples the throughput of ENCO in the $50km/hr$ scenario. Most importantly, MENCO holds a reasonably consistent performance across the scenarios. DAV struggles in these tests due to its throughput averaging mechanism and lack of proper awareness of the distributed environment.

Looking at the PSNR values achieved in Figure. 5, MENCO and ENCO perform equally when stationary. This occurs despite ENCO having higher average throughput. It can be concluded from this that the MENCO fast request mechanism is working to rapidly retrieve segments at stable rates in order to maintain quality. This brings the observed throughput down due to the maintained quality level. ENCO is only requesting segments as needed, more accurately reflecting the available throughput. Both MENCO and ENCO drop approximately 50% in PSNR when mobility is introduced. However, MENCO maintains a stable value around 20dB between $25km/hr$ and $50km/hr$, unlike ENCO which drops a further 50%.

VI. Conclusions and Future Work

This paper proposes a Mobile aware Quality-oriented Co-operative Multimedia Delivery Solution (MENCO) for a distributed heterogeneous environment. Host selection is evaluated by considering the location and velocity of neighbours in relation to the client device. The most suited host will be least likely to move out of communication range before delivering the requested content. Testing using the NS-3 environment shows that MENCO outperforms the comparative studies when mobility is introduced with throughput improvements of up to 100%. The greater stability of MENCO as the speed grows shows the potential of the mobility awareness introduced to the architecture. It is noted that MENCO struggles in a stationary scenario when compared to the original work, ENCO.

Future work will consider collaboration of the two solutions, MENCO and ENCO, to further improve the distributed architecture performance. Further comprehensive testing will be performed to analyse the performance of the solution under a wider range of speeds and conditions including measurement inaccuracies and differing network technologies.

Acknowledgement

This work was supported in part by the Irish Research Council Enterprise Partnership postgraduate scheme under grant number EPSPG/2015/111, Dublin City University and European Union's Horizon 2020 Research and Innovation programme under Grant Agreement no. 688503 for the NEWTON project (http://newtonproject.eu).

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