A Location Coordinate-based Video Delivery Scheme over Wireless Mesh Networks

Quang Le-Dang, Jennifer McManis and Gabriel-Miro Muntean
Performance Engineering Laboratory, Network Innovations Centre, RINCE Institute
School of Electronic Engineering, Dublin City University, Ireland
Emails: quang.ledang2@mail.dcu.ie, jennifer.mcmanis@dcu.ie, gabriel.muntean@dcu.ie

***Abstract*— In this mobile-centric era, users expect ubiquitous access at low cost to an ever increasing range of applications requiring increasingly high data connection speeds. Wireless Mesh Network (WMN) technology provides support for data access over a relatively large area at a modest cost while also being easy and flexible to deploy. Unfortunately, WMN performance is sensitive to load, and applications such as video on demand are likely to stress the network. In response to this, approaches to balance traffic load, such as peer-to-peer solutions are very promising. However, in order to work efficiently, these solutions require not only availability awareness, but also knowledge about location of peers and services. This paper presents a wireless coordinate-based location-aware overlay mechanism for locating and retrieving requested video segments from the nearest peers in order to improve retrieved video quality in WMN. In comparison to the original overlay schemes, our mechanism has significant benefits in both overlay communication efficiency and data retrieval efficiency. Simulation results in both regular and random video segment placement scenarios show how the proposed peer-to-peer video delivery solution for WMN outperforms existing state-of-the-art solutions in terms of video quality and packet loss with different background traffic loads and replication rates.**

***Index Terms*— Video delivery, Video on Demand, Wireless mesh networks, Location-aware overlay, Chord.**

I. Introduction

Since its first introduction and commercialization in 1997, Wireless Fidelity (Wi-Fi) has made a huge leap forward to become the most widely used wireless data access solution today. While the number of Wi-Fi hotspots is increasing on a daily basis, from a user's perspective, they appear to be just a collection of isolated "data oases". In order to become a ubiquitous coverage access network, these oases need to be connected together to form an infrastructure. This idea underlies Wireless Mesh Network (WMN) technology that provides a wireless backbone of Mesh Routers (MR) for providing data connectivity and services to the Mesh Clients (MC) or user devices. Lately, due to numerous deployments in community and metropolitan networks, WMNs have attracted many researchers trying to increase the achievable bandwidth, reduce interference [1]-[2] or enable sophisticated resource allocation techniques for supporting user or operator-specific applications such as VoIP, live video streaming, etc. [1], [3]-[4].

In this paper, we consider the use of WMNs for video

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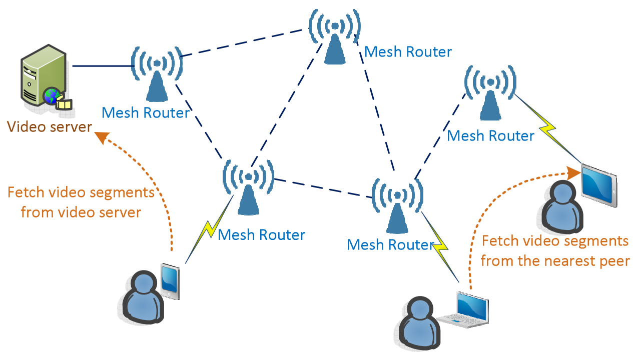


Figure 1: Location-aware overlay for video distribution.

exchange, such as Video-on-Demand (VoD). For these types of applications, Peer-to-Peer (P2P) resource sharing has proved to be a promising solution by providing scalable content distribution. However, in a wireless multi-hop scenario, since the data rate between peers degrades sharply with the number of intermediate nodes between them [5], the constructed peer-to-peer overlay has not only to be aware of the status and availability, but also of the physical location of the peers. The benefits of such location-aware overlay are two folds. First, it makes overlay communications more efficient as overlay messages can be directed to peers based on location rather than having to potentially travel across the entire network as in traditional overlay protocols such as Chord [6], CAN [7], Pastry [8] and Viceroy [9] which are widely used in wired networks. Second, with the aid of location-awareness, when multiple copies of popular content items are spread across the network, overlay peer can identify the closest peer with the appropriate content, significantly improving the quality of service as shown in Figure 1.

In order to improve the quality of overlay video delivery, this paper proposes *WILCO+ - a Wireless Location-aware Chord-based Overlay mechanism for WMN*. WILCO+ uses WILCO's [10] geographical multi-level Chord-ID assignment and finger table to improve lookup efficiency. WILCO+ introduces *a new geographical coordinate-based video segment seeking algorithm*, which replaces WILCO's hierarchical segment seeking algorithm, simplifying the location and retrieval of video segments from the closest peers. Analysis results are presented to show the superiority of WILCO+ in terms of overlay communication efficiency and data retrieval efficiency. Simulation results in both regular and random segment placement scenarios show how WILCO+ improves the quality of video delivery over WMN in terms of average user perceived quality levels and packet loss with different levels of background traffic and segment replication rates.

The rest of this paper is organized as follows. Section II presents the related works in the literature. Section III briefly summarizes basic operations of the Chord and WILCO protocols. Section IV describes the proposed WILCO+ location-aware video segment seeking algorithm. The overlay communication and data retrieval efficiency are detailed in Section V. Section VI presents and analyses the simulation results. Finally, Section VII concludes the paper.

II. Related Works

Wireless mesh networks have been touted as a means to enable low-cost, flexible data access networks. However, in comparison to wired networks, they are more sensitive to loading and prone to provide lower levels of Quality of Service. In this context, when attempting to provide resource intensive services such as streaming video, it is desirable to both minimize the impact of traffic on the network and attempt to improve quality of delivery for users attempting to access data. As a result, the use of overlay networks to provide Peer-to-Peer sharing or caching of video content is highly promising. In particular, if the overlay is location aware, it may be used to try to minimize the distance across which the user seeks the content and over which the content is delivered.

Significant research effort has been expended in the area of overlay network maintenance over wireless networks. This work may be contrasted with that of overlay maintenance in wired networks where the goal is to compromise between the number of messages sent when seeking information and the amount of information any individual node must maintain regarding their peers. Chord [6] is a widely used application-layer overlay which enables relatively efficient resource storage and lookup. All peers have associated IDs and are ordered in an ID circle of modulo 2^m entries (known as a *Chord ring*). For efficient overlay routing, each peer maintains a finger table which stores addresses of m other peers with IDs $(i + 2k \bmod 2m\ (1 \le k \le m)$. Searching for information takes $O(m)$ messages. Typically, for wired networks the overlay is not concerned with peer location, and hence the distance travelled by individual messages.

In the context of multihop wireless networks, however, it is well known that data delivery degrades significantly in terms of bandwidth and delay with the increase in number of hops between sending and receiving nodes [5]. Thus, it is desirable in this case, that the overlay topology have some awareness of the underlying network architecture in order both to minimize the impact of overlay maintenance (in the form of message volume and hop count) on the network and optimize delivery quality (by minimizing search time and optimizing the route the data take through the network).

Significant work has been done to attempt to reduce the impact of overlay maintenance on the network. These approaches are detailed in [11]. Ultimately, for the purposes of scalability, geographical information must be taken into account. In [12]-[14] geographical hash tables are based on CAN. In these works search may be directed at a specific geographical location, reducing overlay maintenance overhead. However, none of these works consider the issue of data retrieval. Indeed, data may be stored far from the source peer, leading to an overhead in updating data and making this class of solutions unscalable. In [15] the authors enhanced a Viceroy overlay with a geographical ID mapping. [16]-[17] extended the same ID mapping scheme to Chord and proposed a cross-layer mechanism to reduce the lookup time. However, these schemes only focus on the control plane of the overlay, and do not address the issue of improving data retrieval quality.

In addition to improving the efficiency of the overlay itself, many studies have been proposed aiming at improving the quality of data delivery. All of these solutions rely on a number of copies of the data being available from different peers within the networks. They then seek to make the overlay aware of properties of the underlay network in order to select the best peer for data retrieval. In [18], the authors proposed Wi-Share, a path quality aware P2P file sharing for mobile Ad-hoc network. In Wi-Share, search requests are broadcasted to the entire network to record path quality to all the possible destination peers. A composite metric of hop count, battery and traffic load was used to select the best peer. In [19], the authors proposed P2PMesh, a structure-based overlay for file sharing over WMN. In the proposed scheme, the MRs are equipped with high storage capability to cache the shared file. To select the best provider, the MR to which the requester is connected tests all the potential providers and select the one with the lowest round trip delay. To minimize route coupling, P2PMesh enable peers that are downloading the same file from the same provider at the same time to share the wireless link. However, these methods of network probing may not provide an accurate reading of network status since the probe packets are sent only once. Moreover, since the probe packets are usually broadcast to the entire network, this class of solution introduce very high overhead and hence is not scalable.

For overlay video applications, users can seek to any watching point according to their interests. As a result, reducing seeking delay introduces an additional challenge for this type of application. In [20], the authors proposed VMesh, a distributed VoD streaming scheme for supporting random users' seeking functionality. To support user interactivity, each peer keeps a list of the peers who have the previous and the next segment of the one it currently stores. The authors show that when the seek distance is not very far from the original segment, traversing this chained list can reduce the seeking delay. In [21], the authors proposed QUVoD, an overlay-based VoD service in urban vehicular network environments. The QUVoD architecture comprises of two layers, the lower layer supports data communications through VANET and the higher layer supports overlay maintenance traffic over 4G networks. To speed up the seeking operation, a distributed grouping-based video segment storage was proposed. A load-balancing scheme was further proposed so that downloading sessions are evenly distributed among the members in a group. However, these solutions do not integrate the underlay topology into the overlay and hence non-optimal underlay routing can significantly affect the retrieved video quality.

Recently, we proposed WILCO [11], a location-aware overlay and video segment seeking mechanism on WMN. The WILCO segment seeking algorithm [10] was proposed based on the WILCO multi-level ID mapping, making use

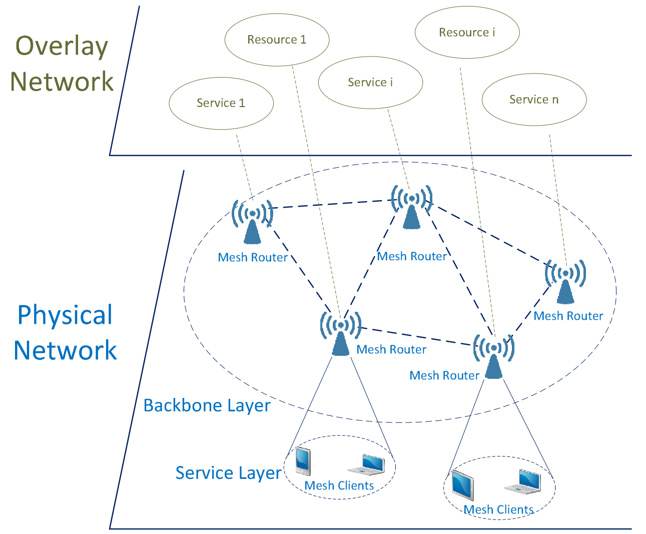


Figure 2: WILCO+ network architecture.

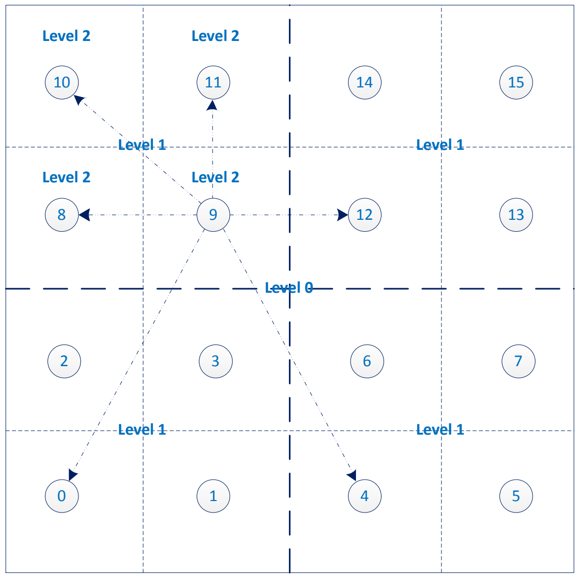


Figure 3: WILCO location-aware ID mapping for *m*=4.

of its multi-level area boundary to locate geographically closer peer to get the segment from. However, while this algorithm show improvements over non-location aware solutions, sub-optimal underlay routing may happen when the source and destination peer are located in different multi-level areas but are close together geographically. As a result, while the scheme works well when the segments are uniformly geographically distributed, it may not suitable for more general scenarios with randomly distributed segment placement.

III. WILCO+ Location-Aware Overlay in WMN

WILCO+ provides a location-aware overlay solution for WMNs, which improves upon WILCO's video content delivery performance by selecting as sources for the retrieval of video segments those which are the closest nodes to the destination in terms of physical location. The WILCO+ algorithms eliminate the anomalies in WILCO which might lead to non-optimal source selection. Intuitively, this will act to reduce the number of hops a segment must traverse, producing benefits in loss and delay statistics, as well as improving global network performance. WILCO+ enhances the classic Chord-based overlay approach [6] and makes use of WILCO's innovative location-aware ID mapping and finger table. WILCO+ seeks to improve on the performance of WILCO, by directly calculating the approximate hop distance between nodes. For reference, this section first presents the network architecture which enables WILCO+'s video sharing, and then, the basic principles behind the Chord and WILCO solutions, WILCO+ relies on. More details regarding WILCO can be found in [10] and [11].

A. *WILCO+ Network Architecture*

In order to accommodate location-oriented and performance-aware video content distribution over WMNs, WILCO+ relies on a two layer architecture as illustrated in Figure 2. The service layer enables MCs to both share video services and resources and use those shared by other MCs. The backbone layer includes stationary, power-unlimited MRs running WILCO+ which form a location-aware peer-to-peer overlay used for accessing the video resources.

When performing video distribution, each video is assigned a unique *key* according to the HASH algorithm and the keys are managed by the MRs according to the Chord mechanism [6]. In order to support efficient video delivery in the peer-to-peer overlay, each video is divided into equal size segments which have assigned segment sequence numbers reflecting their playback order. During the distribution process, it is assumed that segments of the video will become available in several places within the WMN. The locations of the segments are registered and periodically updated at the MR which manages the video in a database with the following structure $[ID_i, S_i, L_i]$ where ID_i is the ID of the MR through which the MC connects to the network; S_i is the start segment sequence number stored at the node and L_i is the number of segments the node stores. It is noted that the structure $[ID_i, S_i, L_i]$ does not assume a single long continuous chunk of segments but instead can accommodate several discrete chunks of segments by utilizing several entries with the same ID_i.

In order to protect from single node failures, the successor of the MR which manages the *key* also stores and updates a copy of this database. When a peer requests segment S_j, the MR searches its database and replies to the requesting peer with the set of peers that have the segment ($S_j \in [S_i, S_i + L_i$). Based on the IDs, WILCO+ video segment seeking algorithm is performed to select the peer located node closest to the requesting peer in terms of hop count to retrieve the segment from.

B. *WILCO location-aware ID mapping*

Enhancing the Chord ring node management structure, WILCO+ employs a WILCO quad tree-like structure and its location-aware ID mapping [10]. A planned WMN with $N = 2^m$ stationary MRs positioned in a grid manner is considered (i.e. MRs are almost equidistant from each other). This grid-like WMN provides the best balance between MR density, backbone connectivity and network capacity [22]. Note that as MRs are assumed stationary, the ID mapping needs to be done only once at planning stage and remains unchanged thereafter.

In successive $\log_4 N$ steps, the deployment area is divided into N areas, each containing one MR, which will be assigned a unique ID. This is done as at every step *i* each of the four areas (i.e. level *i* areas) gets assigned a unique pair of bits which are added as most significant bits to the ID of all MRs located in that area. Level 0 area covers the entire

WMN and the level $\log_4 N$ areas contain a single MR each. Figure 3 illustrates the WILCO location-aware ID mapping for 16 MRs ($m = 4$) and the resulting level 0, 1 and 2 areas.

Note that in each step, each of the areas considered in the previous step is divided into 4 equal-sized areas, and hence, the number of MRs in an area at level i is $N_i = 4^{\frac{m}{2}-i}$.

WILCO allocation ensures that MRs that are close to each other in the physical topology have close IDs numbers and therefore are also close to each other in the overlay. Moreover, as each area at level i contains a quarter of the number of MRs at level $(i-1)$, the maximum number of physical hops between two MRs at level i is half of that between two MRs at level $(i-1)$. This fact plays a central role in WILCO solution and which determines reducing the underlay hop count and hence, improves the lookup performance.

In order to benefit from the location-aware ID mapping, WILCO+ makes use of a WILCO finger table of $3 \times \log_4 N$ entries [10]. Starting from the highest level ($\log_4 N - 1$), at every level i, each MR maintains three entries (fingers) pointing to MRs with the lowest ID in each of the other level i areas with which it shares the same level $(i-1)$ area. For example, the finger table of MR 9 in Figure 3 (illustrated with dash-dot arrows) is as follows: Level 1 fingers - 8, 10, 11; Level 0 fingers - 0, 4, 12.

The finger table of MR with ID p at level i $(0 \le i < m/2$ can be expressed as in equation (1)

$$\text{Let } ID = N_{i-1}k + \left\lfloor \frac{p}{N_{i-1}} \right\rfloor N_{i-1}, \qquad k = 1, 2, 3$$

$$Finger_{i,k} = \begin{cases} ID & ,if \left\lfloor \frac{ID}{N_i} \right\rfloor = \left\lfloor \frac{p}{N_i} \right\rfloor \\ \left\{\left\lfloor \frac{p}{N_i} \right\rfloor + 1\right\} N_i - ID + \left\{\left\lfloor \frac{p}{N_{i-1}} \right\rfloor - 1\right\} N_{i-1}, & if \left\lfloor \frac{ID}{N_i} \right\rfloor \ne \left\lfloor \frac{p}{N_i} \right\rfloor \end{cases} \quad (1)$$

where $N_i = 4^{\frac{m}{2}-i}$ is the number of MRs in an level i area.

Note that similar to a Chord finger table, the WILCO finger table provides higher resolution information at lower level areas (large i) giving priority to MRs in the immediate vicinity of any node than located further.

IV. WILCO and WILCO+ Video Segment Seeking Algorithms

Frequently, P2P VoD solutions rely on some or all portions of a video being available at multiple locations within a network. This may occur due to either to network supported caching of video elements or P2P file sharing. Assuming multiple copies of a video segment are available, intuitively, it would be desirable to minimize the number of hops the retrieved segments must traverse. Both WILCO and WILCO+ utilize geographical information to choose among the segments available. For purposes of comparison, we briefly present the WILCO segment seeking algorithm in addition to the WILCO+ segment seeking algorithms.

In this part, we denote r as the ID of the requesting peer and $\{d_j, j = 1, \dots, k\}$ and the set of destination peers that store the requested video segment, where d_j is the ID of the destination peer j.

A. WILCO multi-level area border based location-aware video segment seeking [10]

WILCO segment seeking algorithm is based on its location-aware ID assignment and includes three steps as shown in Figure 4.

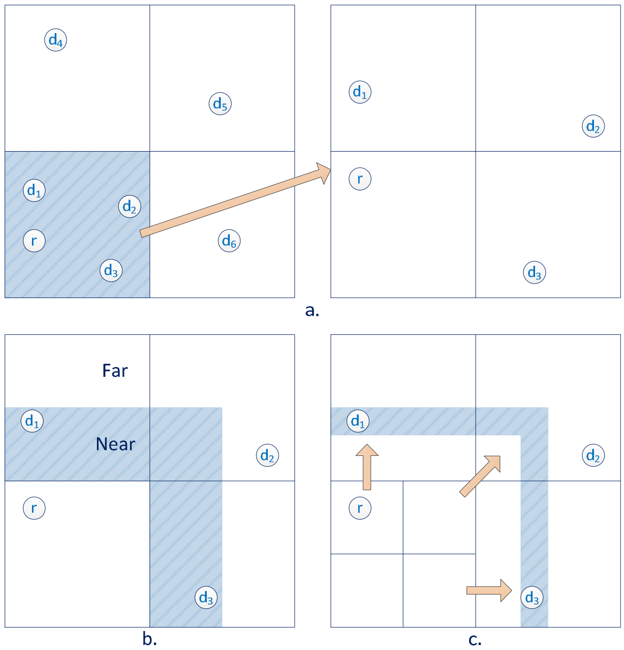


Figure 4: WILCO location-aware segment seeking.
a. Step 1: Coarse selection
b. Step 2: Fine selection
c. Step 3: Tie break

In the first step, a coarse destination set is constructed consisting of all peers sharing the lowest level i_{max} with the requesting peer. Intuitively, this identifies the smallest area shared by the receiver and at least one destination peer. This step is illustrated in Figure 4a.

If there is only one destination peer in d_{coarse}, r chooses this peer to retrieve the video segment, otherwise the algorithm continues.

In the second step, the requesting peer assigns costs to all the destination peers in the coarse destination set based on the distance between the requesting peer area at level $(i_{max}+1)$ and the destination peer. Based on these costs, r retains only the destination peers with the minimum cost in the define destination set d_{fine}.

This set of destinations form a collar around the level $(i_{max}+1)$ area containing r as shown in Figure 4b.

Finally, if there are more than one destination peer in d_{fine}, the algorithm continues with the tie break step. In this step, the level $(i_{max}+1)$ area containing r is divided into 4 equal level $(i_{max}+2)$ areas and depending on which area r resides in, r prefers to select the destination peer which is adjacent to the requesting peer's subarea. WILCO's tie break step is illustrated by the arrows in Figure 4c.

B. WILCO+ coordinate-based location-aware video segment seeking algorithm

In contrast to the WILCO location-aware segment seeking algorithm, the WILCO+ segment seeking algorithm first extracts the coordination information of the requesting and destination peer based on WILCO location-aware ID assignment by using their overlay IDs. The distance in terms of hop count between the two peers is then calculated approximated using the Euclidean distance as in (2).

$$distance^2 = (x_r - x_j)^2 + (y_r - y_j)^2 \quad (2)$$

Where x_r, x_j and y_r, y_j are the x and y coordinates of the two MRs.

Let us recall WILCO location-aware mapping as in Section III B that each step consecutively assigns two bits of the MR ID with the division on y axis decides the first bit and the division on the x axis decides the second bit. As a result, the odd bits from WILCO ID represent the y coordinate while the even bits represent the x coordinate. To determine the distance between the requesting peer and a destination peer j, Pythagorean Theorem can be applied using these coordinate information. Since each lowest level area contains only one MR, this distance resembles the number of hops between the two peers. As a result, using only overlay IDs the requesting peer can easily find the closest destination peer to get the video segment from by performing WILCO+ segment seeking algorithm as shown in Algorithm 1.

In comparison with the segment seeking algorithm in WILCO, WILCO+ is simpler and more accurate. The multi-level area border based WILCO segment seeking can be suboptimal by preferring the destination peer in the same area instead of choosing the closer destination but resides in a different area. On the other hand, WILCO+ segment seeking algorithm is based on the coordination extracting from the IDs of MRs which resolves the suboptimal problem in WILCO segment seeking, promises a better retrieved video performance. An illustrative example will be shown in in the next section to give an intuitive clarification to our argument here.

Algorithm 1: WILCO+ coordinate-based location-aware video segment seeking

x_r = even bits extracting from the ID of the requesting peer.
y_r = odd bits extracting from the ID of the requesting peer.
x_j = even bits extracting from the ID of each of the destination peers, $j = 1, \ldots, k$.
y_j = odd bits extracting from the ID of each of the destination peers, $j = 1, \ldots, k$.
for each d_j
$$distance_j^2 = (x_r - x_j)^2 + (y_r - y_j)^2$$
end for
$d_{min} = \{d_j : distance_j^2 = \min\{distance_j^2, j = 1, \ldots, k\}\}$

V. Efficiency Analysis

WILCO and WILCO+ rely on location awareness to improve efficiency in overlay networks. This includes both overlay communication efficiency and data retrieval efficiency. Overlay communication efficiency for WILCO was analysed in [10] and the main results are summarized below, these results apply for both WILCO and WILCO+. The main focus of this work is on data retrieval and its impact on video quality. The location-aware WILCO approach is compared analytically to a non-location-aware approach.

A. Overlay communications efficiency

- **Using WILCO location-aware ID mapping and improved finger table, a lookup for a key requires at most $\log_4 N$ overlay steps**. This is due to the structure of the multi-level ID mapping and WILCO finger table in which each MR maintains three fingers pointing to MRs in each of the other areas different from the area it resides. Using this structure, the lookup message traverses the overlay from the higher to the lower level area until it reaches the destination peer. Since there are $\log_4 N$ area levels, the maximum number of overlay steps is $\log_4 N$. In comparison to Chord, with the maximum number of overlay steps of $\log_2 N$ [6], WILCO reduces this number by half.
- **Symmetric lookup on both directions of the Chord Ring**. Since WILCO multi-level ID mapping which sub-divides the Chord Ring into equal segments at each level and the WILCO improved finger table maintains fingers at each of these segments, the lookup is symmetric on both directions of the Chord Ring. In contrast, Chord fingers are denser in the forward direction of the Chord Ring and sparser in the backward direction [6]. As a result, lookup will take longer and traverse through more overlay hops if the destination peer is on backward direction of the Chord Ring.

B. Data retrieval efficiency

Consider a WMN of N MRs using WILCO location-aware ID mapping. Assume that the number of replicas of a video segment is n and these are uniformly distributed over the network.

- **Non-location-aware approach.**

In this approach, since the requesting peer has no reference on which peer is better, it can randomly choose any destination peer to retrieve the segment from or select the destination peer in a round-robin fashion to evenly distribute the traffic load as in QUVoD [21].

Since the network size is N, the network diameter is $\sqrt{N}$ hops. As the destination peer is picked randomly, the distance between the requesting and the destination peer in general is

$$d_{NLA} = \sqrt{N} \quad (3)$$

It can be seen from this result that the number of segment replicas does not play a role in (3). As a result, even when replica rate is high, the hop distance between the source and the destination peer is unlikely to reduce and hence, the data retrieval performance is unlikely to improve. Another important remark from (3) is that since the number of segment replicas does not contribute to (3), a non-location-aware overlay segment retrieval strategy should perform no better than the single server strategy where a single server is used.

- **WILCO segment seeking location-awareness**

Let us recall that the number of MRs in a level i area is $N_i = 4^{\frac{m}{2}-i}$, the area diameter is $\sqrt{N_i} = 4^{\frac{1}{2}\left(\frac{m}{2}-i\right)}$ hops. The probability that there is at least one destination peer which has the requested segment resides in the same level i area with the requesting peer is

$$\Pr_i = 1 - (1 - \mathrm{P}_s)^n = 1 - \left(1 - \frac{N_i}{N}\right)^n \quad (4)$$

where $\mathrm{P}_s = \frac{N_i}{N}$ is the probability that the destination peer which has the requested segment resides in the same level i area with the requesting peer if there is only one segment available.

Table 1: WILCO+, WILCO and Chord overlay communication and data retrieval efficiency comparison.

	Overlay communication efficiency		Data retrieval efficiency
	Max overlay steps	**Symmetric lookup**	**Hop distance between requesting and destination peer**
WILCO+	$\log_4 N$	Yes	Nearest destination peer
WILCO			$4^{\frac{1}{2}\left(\frac{m}{2}-i\right)}$ hops with probability $\Pr_i = 1-\left(1-\frac{N_i}{N}\right)^n$
Chord	$\log_2 N$	No	$\sqrt{N}$ hops

Let X_i's be the areas at level i that both the destination peer and the requesting peer resides in, and x_i's are the corresponding area diameters. Since WILCO segment seeking algorithm prefers the destination peer which share the lowest level area with the requesting peer, the hop distance between the requesting peer and the destination peer according to WILCO algorithm is

$$d_{WILCO} = \min\{x_i\} \quad (5)$$

As illustrated in (4), when the number of segment replicas increases, the probability of having both the destination and the requesting peer resides in the same level i area increases. Applying Bernoulli's inequality to the left side of (4) as shown in (6), this increase rate is at least linearly with the number of segment replicas. As a result, WILCO does not only capable of finding the closer peer to retrieve the segment from according to WILCO multi-level area structure but can also make use of the segment replica rate to improve its data retrieval efficiency.

$$\left(1-\frac{N_i}{N}\right)^n \geq 1-\frac{nN_i}{N} \quad (6)$$

- **WILCO+ segment seeking location-awareness**

Since the location-awareness of WILCO is based on WILCO multi-level area border, suboptimal selection may happen. For instance, consider a network layout as in Figure 5, where the requesting peer is at node 15, the two destination peers are resides at node 0 and 26. In this scenario, using WILCO segment seeking algorithm, the requesting peer will pick destination peer 0 to download the segment from as they share the same lower level area although node 26 is actually the closer destination peer. This border effect may be severe when the network size is large or when the segments are randomly distributed.

WILCO+ is designed to overcome this limitation. By extracting the location coordinate information from the MR's ID, the exact distance in terms of hop count is determined as in (2). Upon comparing this distance, the closest destination peer can be accurately determined. Using the same example as above, requesting peer at MR15 will choose MR26 to retrieve the segment from according to WILCO+ due to the closer hop distance.

The comparisons of WILCO, WILCO+ and the original Chord in terms of overlay communication and data retrieval efficiency are summarized in Table 1.

VI. Simulation-Based Testing

The performance of WILCO+ is evaluated using Network Simulator NS-3 [23]. The video quality retrieval performance of WILCO+ is compared to that of WILCO, a server-only solution (*Server*) in which the video segments are obtained from only the server, and the state of the art QUVoD algorithm. Peak Signal-to-noise Ratio (PSNR), Mean Opinion Score (MOS) and packet loss are compared in two segment placement scenarios with different background load and replication rates.

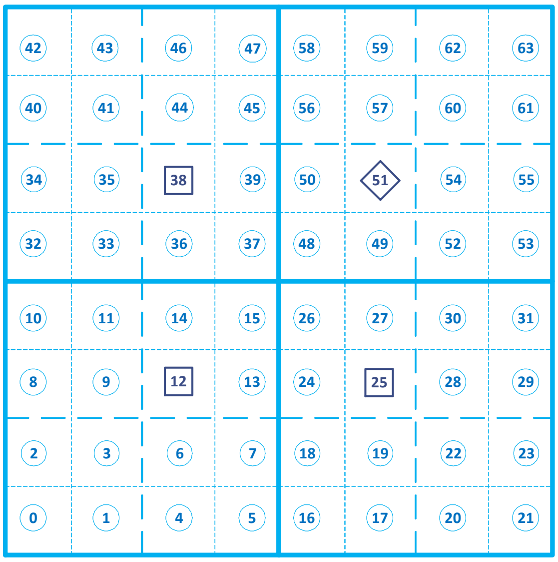


Figure 5: Simulation scenario with server and replica placements as in the first Scenario.

The simulated topology follows the description from Section III.B, and consists of $N = 64$ MRs arranged in an 8x8 grid, with the distance between two adjacent MRs set to 100m as depicted in Figure 5. In the simulations, all MRs are equipped with IEEE 802.11b radios and OLSR routing protocol is used.

In our simulations, real video trace files are used to simulate the retrieval of three video segments ($S = S1, S2, S3$ by each of the overlay peers. The video bit rate is 341Kbps; each segment is 10 seconds long and about 0.44MB in size. Each simulation is repeated 10 times and the results are averaged.

Throughout our simulations, otherwise stated, the number of replicas for each video segment is three. The video server is located at MR 51 (diamond node in Figure 5) and contains all three video segments. Regarding the placement of the replica segments, two scenarios are considered. Scenario 1 represents content replication by a network operator. In this case, replicator server are spred evenly throughput the network. For this scenario, video segments are partly available at MR 12 ($\{S_1, S_2\}$), 25 ($\{S_2, S_3\}$) and 38 ($\{S_3, S_1\}$) (square nodes in Figure 5). It is important to note that not all video segments are available at these replicators.

Scenario 2 represents P2P content sharing via an overlay network where video segments are only stored in the user's storage. In this scenario, the replicas of each segment are randomly distributed across the network.

A. *Video retrieval performance with no background load*

We first analyze the performance of WILCO+ with segment placement as in Scenario 1 with no background traffic. Table 2 shows the average PSNR and packet loss results when WILCO+, Server and QUVoD are employed in turn. Using Server as the baseline, the numbers in brackets show the improvement of the mentioned scheme from the baseline.

Table 2: PSNR and packet loss comparisons.

		WILCO+	QUVoD	Server
PNSR (dB)	Average PSNR	39.72 (+75%)	25.64 (+13%)	22.70
	PSNR Variance	12.23 (-27%)	17.31 (+4%)	16.66
Average Packet Loss (%)		2.17 (-82%)	8.38 (-29%)	11.81

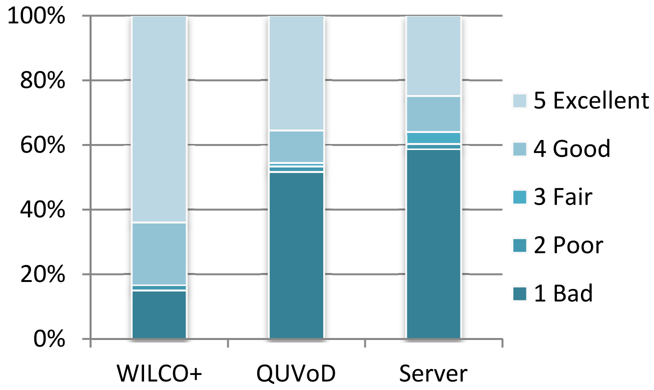


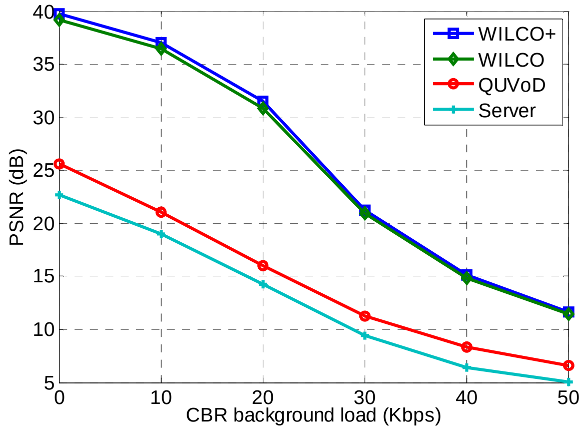
Figure 6: MOS distribution of WILCO+, QUVoD and Server.

It is observed that WILCO+ outperforms both schemes significantly by a huge margin of more than 14dB in average PSNR (75% improvement). Moreover, the PSNR variance of WILCO+ is also the lowest among the three compared schemes with roughly a 4dB difference (25% improvement). These results illustrate that the video quality delivered by WILCO+ is not only the highest, but also the most consistent across the peers. Using t-test with confidence level of 99% it can be said that there is a statistically significant difference in favor of WILCO+ in PSNR when applying pair-wise comparison between WILCO+ results and those of the two other schemes. This improvement is achieved due to WILCO+'s ability to intelligently choose the nearest peer to get the video segment from, greatly improving the throughput. Table 2 also shows that packet loss is the lowest in the case of WILCO+ with more than 5 times lower than the baseline and 3 times lower than QUVoD. As packet loss is one of the key factors that decide the received video quality level, this result confirms the PSNR-based evaluation and gives another view on the effectiveness of WILCO+.

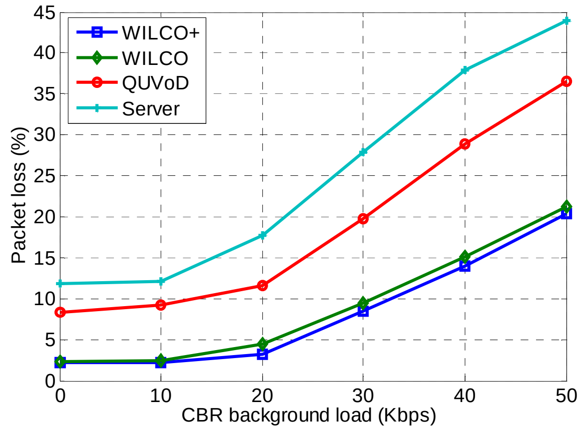
The MOS distribution of the video streams of the three schemes is investigated to show the distribution of perceived video quality across different users. Perceived video quality levels are mapped from the PSNR results according the recommendation in [24]. Figure 6 demonstrates that the user perceived video quality level is the best when WILCO+ is employed with 67% of the video streaming sessions having "excellent" quality, outperforming the two compared schemes by roughly 30%. In addition, while in the case of WILCO+ only 12% of users suffer from "bad" videos, this figure is more than 50% for the compared schemes, clearly revealing the consistency of WILCO+ in video quality retrieval.

B. Video retrieval performance with background traffic

We further evaluate the performance of WILCO+ with different background traffic loads in both Scenarios. The video retrieval performance of WILCO+ is compared against WILCO, QUVoD and Server. To simulate background load, $N/4$ constant bit rate (CBR) streams are generated between $N/2$ randomly selected source and destination peers. The load of the background streams are varied from 0 (no load) to 50Kbps.



a.



b.

Figure 7: PSNR and packet loss comparisons in regular segment placement with different background loads.

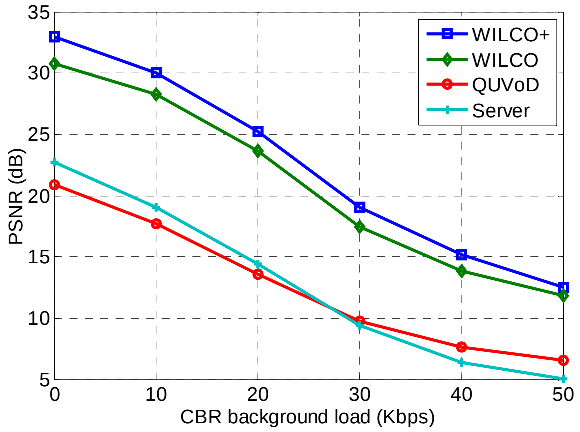
a. PSNR comparison.

b. Packet loss comparison.

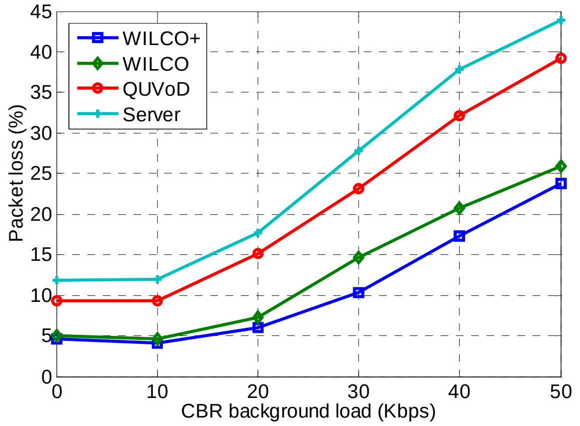
Figure 7a illustrates the PSNR performance of the four schemes in the regular segment placement. It is observed that for all the background load levels, WILCO+ and WILCO outperform the two other schemes by a significant gap of at least 50%. This improvement is most pronounced when the background load is low to moderate (≤30Kbps) where WILCO+ and WILCO improve the received video quality by more than 10dB. When the background traffic is heavy, the PSNR performance of all schemes reduces rapidly and the video quality becomes very bad anyway. It is interesting to see that the difference between QUVoD and Server approaches is not very substantial across all the CBR loads. This clearly shows that overlay over wireless multi-hop network, especially on WMN, cannot greatly improve the video delivery quality without consideration of location information. Figure 7b confirms this result, showing that WILCO+ and WILCO significantly reduce the packet loss by at least 50% compared to the two other schemes.

In comparison with WILCO, WILCO+ is always better but only by a very small margin of about 0.5dB in PSNR. This is because with the regular segment placement, video segments are almost uniformly distributed geographically across the network and the multi-level area border suboptimal issue is not pronounced.

However, the PSNR performance changes drastically when the video segments are distributed randomly (Scenario 2) as illustrated in Figure 8a. It is observed that the retrieved video quality reduces significantly for all the peer-to-peer schemes due to the suboptimal segment placement.



a.



b.

Figure 8: PSNR and packet loss comparisons in random segment placement with different background loads.

a. PSNR comparison.

b. Packet loss comparison.

However, WILCO+ and WILCO are able to retain a very high PSNR of over 30dB, greatly outperform the other two schemes. The random segment placement clearly reveals the superiority of WILCO+ in comparison to WILCO where it outperforms WILCO by roughly 2dB throughout the background loads. This is because the multi-level area border based WILCO segment seeking tends to prefer a more distant destination peer that resides in the same area to a closer peer but is in a different area.

It is interesting to observe that according to Figure 8a, QUVoD is inferior to Server when the video segments are randomly placed with light background load. When the background load is high, QUVoD becomes better than Server but the achievable PSNR is already very low. This result agrees with our data retrieval efficiency analysis in Section VI that that on wireless multi-hop networks, deploying P2P services "as is" without considering the physical topology is not better than using single server for all overlay peers.

The better packet loss figure of QUVoD in Figure 8b can be explained by the fact that in the *Server* scheme, all the peers get video segments from the server, hence, the peers which are close to the server can get high videos with very little packet loss while the peers far away basically get very low quality video with high loss. As the result, on average, the PSNR quality of Server is better than QUVoD but its packet loss performance is worse. On the other hand, the round-robin peer selection of QUVoD makes the quality and packet loss variation among the peers less pronounced but

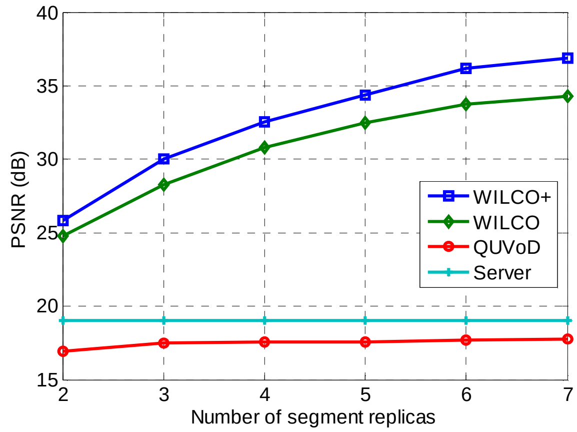


Figure 9: PSNR comparison with different number of segment replicas.

on average, its PSNR performance is worse.

In addition, the average hop distance between the requesting and destination peer of WILCO and WILCO+ was also calculated in the simulation to further demonstrate the superiority of WILCO+. Our results indicate that this figure of WILCO is 2.4 while that of WILCO+ is 2.2. These figures shows an approximately 10% reduction in terms of hop length between requesting and destination peer with WILCO+ which is the result of the better location-awareness in video segment seeking algorithm.

C. Video retrieval performance with different number of segment replicas

We further investigate the effect of the number of segment replicas to the achievable PSNR of the four considered schemes. In this simulation, the random segment placement is considered for its generality with background load of 10Kbps. The number of segment replicas varies from 2 to 7 (10% replication rate). It is noted that in this scenario, the replication rate does not affect the performance of Server scheme since overlay peers get all the segments from the server anyway.

As shown in Figure 9, when the number of segment replicas increases, the PSNR performance of all P2P schemes also increases. Among all the schemes, WILCO+ does not only perform the best but its rate of increase is also the most pronounced with more than 10dB (37% improvement) as the number of replicas increases from 2 to 7. The PSNR gap between WILCO+ and WILCO increases from roughly 1dB to 3dB with the number of segment replicas illustrates that WILCO+ can make a better use of location information than WILCO.

From Figure 9, it is interesting to see that the PSNR performance of QUVoD does not noticeably increase with the number of segment replicas and is even worse than that of Server. This can be explained by its round-robin based peer selection which does not consider the location of peers. As the result, peers may end up seeking for a distant destination peer to get the segment from even when the replication rate is high. This result also agrees with our data retrieval efficiency analysis in Section VI.

VII. Conclusion

This paper proposes WILCO+, which includes a novel coordinate-based location-aware segment seeking algorithm for Chord-based video distribution overlay over WMN. The proposed scheme embeds the location information of MRs in their overlay ID and uses it to locate and retrieve requested video segments from the nearest peers in order to improve video quality. Analysis results show that WILCO+ can greatly enhance both the overlay communication efficiency and data retrieval efficiency. Our simulation results show that WILCO+ significantly improves video delivery quality up to 50% in comparison with other solutions in terms of PSNR with different background loads and replication rates. Our future work includes the proposal of an adaptive overlay video streaming algorithm which will work along with WILCO+ to further enhance video retrieval in the case of high background traffic load.

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Quang Le-Dang was awarded his B.Eng. degree in Telecommunications from Hochiminh City University of Technology, Vietnam in 2006 and his M.Eng. degree in Telecommunications from McGill University, Canada in 2010. He is currently working towards his PhD as a researcher with the Performance Engineering Laboratory in Dublin City University, Ireland. His research interests include methods for constructing overlays over Wireless Mesh Network and location-aware multimedia delivery.

Jennifer McManis received her PhD for research on verification and control of real-time discrete event dynamical systems from University of California, Berkeley in 1993. She is a Lecturer in the School of Electronic Engineering, DCU and co-Director of the DCU Performance Engineering Laboratory. Her research interests are in the area of performance of web-based systems, performance of large-scale software systems, and performance of networks.

Gabriel-Miro Muntean (M'04) received his PhD for research on quality-oriented adaptive multimedia streaming from Dublin City University (DCU) Ireland, in 2003. He is a Senior Lecturer with the School of Electronic Engineering, DCU, co-Director of the DCU Performance Engineering Laboratory, and Director of the Network Innovations Centre, the Rince Institute Ireland. Dr. Muntean is also Consultant Professor with Beijing University of Posts and Telecommunications, China. His research interests include quality-oriented and performance-related issues of adaptive multimedia delivery, performance of wired and wireless communications, energy-aware networking, and personalized e-learning. He has published over 180 papers in prestigious international journals and conferences, has authored three books and 12 book chapters, and has edited five other books. Dr. Muntean is an Associate Editor of the IEEE TRANSACTIONS ON BROADCASTING, an Associate Editor of the IEEE COMMUNICATIONS SURVEYS AND TUTORIALS, and reviewer for other important international journals, conferences, and funding agencies. He is a member of the ACM, IEEE and the IEEE Broadcast Technology Society.