A SCHEME FOR EFFICIENT PEER-TO-PEER LIVE VIDEO STREAMING OVER WIRELESS MESH NETWORKS

BEHRANG BAREKATAIN

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To our prophet, ***Mohammad***, the messenger of truth, fraternization and kindness

To my dear and beloved ***wife*** who endured my absence for three years

To my dears 13 and 3 years old ***sons***

To my dears ***mother***, ***father***, ***sister***, and ***brother***

To my dear defunct 20 years old ***brother***

To my dears ***mother-***, ***father-***, *and* ***sisters-in-law***

To my best supervisor, ***Professor Dr. Mohd Aizaini Maarof***

To my best co-supervisor, ***Associate Professor Dr. Alfonso Ariza Quintana***

And to all who supported me in my study

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ABSTRACT

Peers in a Peer-to-Peer (P2P) live video streaming system over hybrid wireless mesh networks (WMNs) enjoy high video quality when both random network coding (RNC) and an efficient hybrid routing protocol are employed. Although RNC is the most recently used method of efficient video streaming, it imposes high transmission overhead and decoding computational complexity on the network which reduces the perceived video quality. Besides that, RNC cannot guaranty a non-existence of linear dependency in the generated coefficients matrix. In WMNs, node mobility has not been efficiently addressed by current hybrid routing protocols that increase video distortion which would lead to low video quality. In addition, these protocols cannot efficiently support nodes which operate in infrastructure mode. Therefore, the purpose of this research is to propose a P2P live video streaming scheme which consists of two phases followed by the integration of these two phases known as the third phase to provide high video quality in hybrid WMNs. In the first phase, a novel coefficients matrix generation and inversion method has been proposed to address the mentioned limitations of RNC. In the second phase, the proposed enhanced hybrid routing protocol was used to efficiently route video streams among nodes using the most stable path with low routing overhead. Moreover, this protocol effectively supports mobility and nodes which operate in infrastructure mode by exploiting the advantages of the designed locator service. Results of simulations from the first phase showed that video distortion as the most important performance metric in live video streaming, had improved by 36 percent in comparison with current RNC method which employs the Gauss-Jordan Elimination (RNC-GJE) method in decoding. Other metrics including frame dependency distortion, initial start-up delay and end-to-end delay have also improved using the proposed method. Based on previous studies, although Reactive (DYMO) routing protocol provides better performance than other existing routing protocols in a hybrid WMN, the proposed protocol in the second phase had average improvements in video distortion of l86% for hybrid wireless mesh protocol (HWMP), 49% for Reactive (Dynamic MANET On-Demand-DYMO), 75% for Proactive (Optimized Link State Routing-OLSR), and 60% for Ad-hoc on-demand Distance Vector Spanning-Tree (AODV-ST). Other metrics including end-to-end delay, packet delay variation, routing overhead and number of delivered video frames have also improved using the proposed protocol. Finally, the third phase, an integration of the first two phases has proven to be an efficient scheme for high quality P2P live video streaming over hybrid WMNs. This video streaming scheme had averagely improved video distortion by 41%, frame dependency distortion by 50%, initial start-up delay by 15% and end-to-end delay by 33% in comparison with the average introduced values by three other considered integration cases which are Reactive and RNC-GJE, Reactive and the first phase, the second phase and RNC-GJE.

ABSTRAK

Sistem aliran video secara langsung Rakan-ke-Rakan (P2P) melalui rangkaian jaringan tanpa wayar hibrid (WMNs) menikmati kualiti video yang tinggi apabila kedua-dua pengkodan rangkaian rawak (RNC) dan protokol rangkaian hibrid yang cekap digunakan. Walaupun RNC adalah kaedah aliran video cekap yang terkini digunakan, ia mengenakan overhed penghantaran yang tinggi dan kerumitan pengiraan pada rangkaian yang mana mengurangkan kualiti video yang diterima. Selain daripada itu, RNC tidak boleh menjamin ketidakhadiran kebergantungan linear dalam matriks pekali yang terjana. Dalam WMNs, nod mobiliti tidak dipertimbangkan dengan secara berkesan oleh protokol penalaan hibrid semasa yang mana ini meningkatkan herotan video. Hal yang demikian menyebabkan kualiti video yang rendah. Tambahan pula, protokol ini tidak boleh secara cekap menyokong nod-nod yang beroperasi dalam mod infrastruktur. Oleh itu, tujuan kajian ini adalah untuk mencadangkan satu skema aliran video secara langsung P2P yang terdiri dari dua fasa diikuti dengan intergasi dua fasa tersebut dikenali sebagai fasa ketiga untuk menyediakan kualiti video yang tinggi dalam WMNs hibrid. Dalam fasa pertama, penjanaan matriks pekali yang novel dan kaedah penyongsangan telah dicadangkan untuk menangani limitasi RNC seperti yang telah dimaklumkan. Dalam fasa kedua, protokol penalaan hibrid yang dipertingkatkan yang telah dicadangkan telah digunakan dengan cekap untuk menghala aliran video antara nod dengan menggunakan laluan yang paling stabil dengan overhed penghalaan yang rendah. Lebih lagi, protokol ini secara berkesan menyokong mobiliti dan nod yang beroperasi dalam mod infrastruktur dengan mengeksploitasi kelebihan perkhidmatan pengesan yang telah direka. Hasil simulasi dari fasa pertama menunjukkan bahawa herotan video yang merupakan matriks prestasi yang penting dalam aliran video secara langsung telah dipertingkatkan sebanyak 36 peratus berbanding dengan kaedah RNC semasa yang menggunakan kaedah penghapusan Gauss-Jordan (RNC-GJE) dalam penyahkodannya. Matriks yang lain termasuk herotan kebergantungan kerangka, awalan permulaan dan lengah hujung-ke-hujung juga telah dipertingkatkan menggunakan kaedah yang telah dicadangkan. Berdasar kepada kajian sebelumnya, walaupun protokol penghalaan (*Dynamic MANET On-Demand*-DYMO) Reaktif memberikan prestasi yang lebih baik berbanding dengan protokol penghalaan sedia ada dalam WMN hibrid, protokol yang telah dicadangkan dalam fasa kedua mempunyai purata pembaikan herotan video sebanyak 186% bagi protokol *Hybrid Wireless Mesh Protocol* (HWMP), 49% bagi Reaktif (DYMO),75% bagi (*Optimized Link State Routing*-OLSR) Proaktif, dan 60% bagi *Ad-hoc on-demand Distance Vector Spanning-Tree* (AODV-ST). Matriks yang lain termasuk lengah hujung-ke-hujung, pelbagai lengah paket, overhed penghalaan dan bilangan kerangka video yang dihantar juga telah dipertingkatkan dengan menggunakan protokol penghalaan hibrid yang dicadangkan. Akhir sekali, fasa ketiga, integrasi fasa pertama dan fasa kedua menunjukkan bahawa ia adalah satu skema yang cekap untuk aliran video secara langsung P2P yang berkualiti tinggi melalui WMNs. Skema aliran video ini secara purata telah menambahbaik matriks herotan video sebanyak 41%, herotan kebergantungan kerangka sebanyak 50%, awalan permulaan sebanyak 15% dan lengah hujung-ke-hujung sebanyak 33% berbanding dengan purata nilai yang ditunjukkan oleh tiga kes integrasi yang dipertimbangkan iaitu Reaktif dan RNC-GJE, Reaktif dan fasa pertama, fasa kedua dan RNC-GJE.

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$A_{1\times n}$ - A matrix of n generated coefficients entries using EMGIM

$A_{n\times n}$ - A diagonal matrix consists of n generated values in $\mathbf{A_{1\times n}}$

a_i - An entry on the main diagonal of a coefficients matrix

B_i - An original block

$B_{n\times n}$ - Original Matrix including *n* *k*-byte not coded blocks

C_i - A coefficients vector

$C_{n\times n}$ - Coefficients Matrix including *n* *n*-byte coefficients vectors

$C^{-1}_{n\times n}$ - Inverted coefficients matrix

$f(t)$ - A function over positives values of t

$GF(2^m)$ - Galois Field of size 2^m

G_G - Number of generated packets using RNC-GJE

G_M - Number of generated packets using EMGIM

k - Block size in bytes

n - Number of original/encoded blocks or coefficients vectors

O	-	Big-O notation for measuring algorithm complexity
P_G	-	Number of encoded blocks in a packet using RNC-GJE
P_M	-	Number of encoded blocks in a packet using EMGIM
$T(t)$	-	Execution time for an algorithm with t inputs
X_i	-	An encoded block
$X_{n \times k}$	-	Encoded Matrix including *n* *k*-byte encoded blocks

LIST OF ABBREVIATIONS

ABR	-	Associative Based Routing
AD	-	Absolute Delay
AODV	-	Ad-hoc On-demand Distance Vector
AODV-ST	-	Ad-hoc On-demand Distance Vector Spanning Tree
AP	-	Access Point
ARP	-	Address Resolution Protocol
ARQ	-	Automatic Repeat Request
AVC	-	Advance Video Coding
BATMAN	-	Better Approach To Mobile Ad-hoc Networking
BM	-	Buffer Map
CDN	-	Content Delivery Network
CI	-	Confidence Interval
CPU	-	Central Processing Unit
DCT	-	Discrete Cosine Transform
DD	-	Dependency Distortion
DH-AODV	-	Directional Hierarchical AODV
DHCP	-	Dynamic Host Configuration Protocol

DHT	-	Distributed Hash Table
DR	-	Delivery Ratio
DSDV	-	Destination Sequence Distance Vector
DSR	-	Dynamic Source Routing
DYMO	-	Dynamic MANET on-demand routing
EED	-	End-to-End Delay
ESM	-	End System Multicasting
EUI	-	Extended Unique Identifier
FEC	-	Forward Error Checking
FIFO	-	First-In-First-Out
FPS	-	Frame Per Second
GARP	-	Gratuitous Address Resolution Protocol
GF	-	Galois Field
GoP	-	Group-of-Pictures
HARQ	-	Hybrid Automatic Repeat Request
HNN	-	Hopfield Neural Network
HOVER	-	Hybrid On-demand Distance Vector Routing
HS	-	Home Server
HWMP	-	Hybrid Wireless Mesh Protocol
IARP	-	Intra Zone Routing Protocol
IBT	-	Initial Buffer Time

IERP	-	Inter zone Routing Protocol
IETF	-	Internet Engineering Task Force
INET	-	Internet Networking
INETMANET	-	Internet Networking MANET
ISD	-	Initial Start-up Delay
ISO/IEC	-	International Organization for Standardization/ International Electrotechnical Commission
ITU-U	-	International Telecommunication Standardization Sector
MAC	-	Medium Access Control
MANET	-	Mobile Ad-hoc Networks
Mbps	-	Mega bit per second
MCMR	-	Mesh-Channel Multi-Radio
MIMO	-	Multi-Input Multi-Output
MN	-	Mesh Node
MPEG	-	Moving Picture Experts Group
MPR	-	Multi Point Relay
MR	-	Mesh Router
MSDU	-	MAC-layer Service Data Unit
MTU	-	Maximum Transfer Unit
NC	-	Network Coding
NIC	-	Network Interface Card
OLSR	-	Optimized Link State Routing Protocol

OMNET++	-	Objective Modular Network Testbed in C++
OSI	-	Open System Interconnection
OVERSIM	-	Overlay Simulator
P2P	-	Peer-to-Peer
PDA	-	Personal Digital Assistant
PDV	-	Packet Delay Variation
PPLive	-	Peer-to-Peer Live Video
PPM	-	Push-Pull Mesh
PPStream	-	Peer-to-Peer Streaming
PRIME	-	Peer-to-Peer Receiver-Driven Mesh-based streaming
PSNR	-	Peak Signal-to-Noise Ratio
QoS	-	Quality of Service
QP	-	Quantization Parameter
RANN	-	Route Announcement
RFC	-	Request For Comments
RNC	-	Random Network Coding
RREP	-	Route Reply
RREQ	-	Route Request
SNCR	-	Source Node Compute Routing
SopCast	-	Streaming over P2P
SP2P	-	Structured P2P

SPT	-	Spanning Tree protocol
STA	-	Station
SVC	-	Scalable Video Coding
TC	-	Topology Control
TCP/IP	-	Transmission Control Protocol/Internet Protocol
TSRP	-	Total Successfully Received Packets
TTL	-	Time-To-Live
TX	-	Transmitter
UAVs	-	Unmanned Aerial Vehicles
UDP	-	User Datagram Protocol
UP2P	-	Unstructured P2P
URR	-	Useful Received Rate
VD	-	Video Distortion
Wi-Fi	-	Wireless Fidelity
WLAN	-	Wireless Local Area network
WMAC	-	Wireless Medium Access Control
WMAN	-	Wireless Metropolitan Area Network
WMN	-	Wireless Mesh Networks
ZHLS	-	Zone based Hierarchical Link State
ZRP	-	Zone Routing Protocol

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CHAPTER 1

INTRODUCTION

1.1 Overview

Video streaming over wireless networks, especially on mobile nodes, has become more popular due to the advances in the network access technologies (Dong-Hoon *et al.*, 2013; Saeed *et al.*, 2013). Video streaming refers to the process of disseminating a live video stream by a source to the network. Then, each node not only receives and playbacks the video stream, but it can also forward it to other nodes in the network. Based on Saeed *et al.* (2013), there will be more than 450 million mobile TV users by 2014 which account for a large amount of traffic over wireless networks. What can be inferred from this prediction is that it is necessary to have an efficient video streaming scheme for preventing the problem of low video quality.

High video quality, the final target of all video streaming schemes (Mirshokraie and Hefeeda, 2010), can be provided by increasing bandwidth utilization and using efficient node-to-node communication as well as video streaming methods (Adamou *et al.*, 2008; Richardson, 2010; Seferoglu and Markopoulou, 2010; Ozturk and Clincy, 2012; Saeed *et al.*, 2013). Beside, nodes in a wireless mesh network (WMN) move moment by moment which results in path failure (Garnepudi *et al.*, 2013). Therefore, an efficient routing protocol is also needed in a WMN for providing better video quality (Nenad *et al.*, 2012). In fact, many packets can be lost using an inefficient routing protocol (Kserawi *et al.*, 2014). In this thesis, *Efficient* means that a method is functioning in the best possible manner in which it causes the least resource wasting as much as possible. Moreover, a method can be *Effective* if it is enough for accomplishing a goal or a purpose and providing the required results.

Bandwidth utilization can be improved using the most recently used video compression standard, the H.264/MPEG-4 (Moving Picture Experts Group), (Richardson, 2010). The video encoder applies the compression rules on video frames before arranging them into groups of pictures (GoPs). Although employing an efficient video compression standard let nodes consume less amount of bandwidth, existing decoding dependencies among video frames can reduce the video quality on receivers (Akbari *et al.*, 2007). In other words, based on the H.264/MPEG-4 standard, it is impossible to playback a successfully received video frame if its reference frame is not decoded yet. So, it is necessary to request the missed reference frame from the video source or a neighbor in the network.

In order to address this problem, peers in a Peer-to-Peer (P2P) network not only download the video stream from upstream peers, but they also concurrently serve the downstream peers by uploading video frames to them (Zhang *et al.*, 2010a). This behavior reduces the effect of frame decoding dependency on the perceived video quality, because peers can immediately request missed video frames (e.g. a reference frame) from their neighbors instead of the video source with lower end-to-end delay. P2P video streaming has been one of great interest (Ramzan *et al.*, 2012). P2P networks can be implemented as an overlay on top of the underlying network (Huang *et al.*, 2007).

A P2P overlay network is based on a distributed architecture in which there are many independent peers who share a portion of their resources such as upload bandwidth. This increases network throughput due to existing cooperation among peers in data streaming (e.g. live video) (Tarkoma, 2010). According to Shen *et al.* (2010), P2P networks can be classified into two classes based on the topology: Tree- and Mesh-based networks. Tree-based networks suffer from low network throughput and resilience in peer churning. Churning means that a peer repeatedly joins and leaves the network (Stutzbach and Rejaie, 2006). Moreover, high reconstruction cost due to peer churning can be imposed on the network. On the other hand, mesh-based networks, which have employed in many previous studies, efficiently address these challenges by increasing the cooperation among peers (Magharei *et al.*, 2007; Moayeri *et al.*, 2012). In fact, each peer can have more than one neighbor in mesh-based P2P networks.

In mesh-based P2P streaming, a peer can concurrently download from more than one upstream peers and simultaneously serve many downstream peers. In this regard, there are always risks that peers receive the same content from their neighbors. Therefore, they need to make the contents held by different upstream peers consistent before downloading. This refers to content reconciliation problem which considerably wastes the limited available bandwidth in peers and increases the network complexity (Chen *et al.*, 2010b).

Network coding (Ahlswede *et al.*, 2000), especially random network coding (RNC) (Ho *et al.*, 2003), efficiently addresses this problem in a mesh-based P2P streaming system, because it omits the need for content reconciliation among peers and makes all video blocks equivalent (Wang and Baochun, 2006; Cleju *et al.*, 2011). Network coding has recently emerged as a promising approach for improving the performance of massive data distribution applications such as file distribution and video streaming (Heide *et al.*, 2012).

Moreover, it has been widely acknowledged and accepted that P2P live video streaming using RNC can increase the throughput of the system (Wang and Li, 2007a; Baochun and Di, 2011). For example, RNC noticeably increases the network resilience in peer churning (Wang and Li, 2007a). Although RNC efficiently addresses the content reconciliation problem in P2P networks, it is impossible to ignore the effect of the employed wireless infrastructure on the perceived video quality. In other words, a stable and reliable infrastructure is also required to mitigate the dynamic conditions of the wireless networks due to interferences, collisions, and node mobility. In this regard, wireless mesh networks (WMNs) has become a promising advanced technology to fulfill this requirement (Gibson, 2013). Self-healing, self-configuration, low up-front cost and easy network maintenance are the most important characteristics of WMNs (Akyildiz and Wang, 2009). Although there are three different classifications of WMNs which are client-based, infrastructure and hybrid (Zhang *et al.*, 2007), hybrid WMNs, a combination of client-based and infrastructure classes, are more realistic in implementation due to this fact that they can include STA and mobile mesh nodes with multi-hopping capability. STA nodes (e.g. Smartphones and PDAs), which operate in infrastructure mode and move with low speed, do not run and perform routing protocol and forwarding operation, respectively. On the other hand, mesh nodes can perform routing and forwarding. *STA node* and *mesh node* in this study are defined in IEEE 802.11 standard (IEEE, 2012) as *a STA node which is associated to an access point (AP)* and *a mesh STA* node, respectively. However, in order to avoid misunderstanding, this research calls them STA and mesh nodes in the rest of this thesis.

1.2 Background of the Problem

Figure 1.1 shows that network coding increases network throughput. Suppose that each link has the capacity of one bit per second. Peer 4 performs a simple XoR logical operation on the received bits A and B, then; it sends one bit XoR(A,B) in one transmission cycle instead of two. This reduces end-to-end delay between the source node 1 and destination nodes 6 and 7. Nodes 6 and 7 can extract bits B and A from bit XoR(A,B) with lower end-to-end delay, respectively. However, according to (Ho and Lun, 2008), RNC is more suitable than XoR-based network coding as follows. In contrary to the XoR-based network coding, RNC is topology independent.

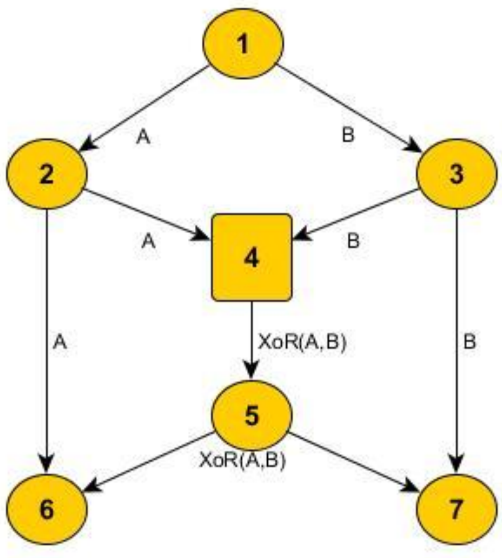

Figure 1.1 Network Coding Efficiency in Streaming

Therefore, the problem of content reconciliation can be happened using XoR-based network coding. RNC provides higher network throughput without the necessity of having global knowledge about the whole network. RNC efficiently exploits the broadcast nature of wireless medium and improves the highlighted guidelines in order to mitigate the side effects of wireless channels.

In Figure 1.2, suppose that source node 1 sends two 8-byte packets P1=1 and P2=2 to the next hop. Peer 5 receives two same encoded packets D1 and D2 using XoR-based network coding and cannot decode P1 and P2 from them. This means that content reconciliation problem can be occurred in XoR-based network coding. So, XoR-based network coding is topology dependent and cannot always increase the network throughput.

On the other hand, using RNC, peers 6 and 7 generates encoded blocks E1 and E2 using four coefficients entries 3, 4, 2 and 7. Peer 5 easily decodes E1 and E2 by solving two linear equations 11=3P1+4P2 and 16=2P1+7P2.

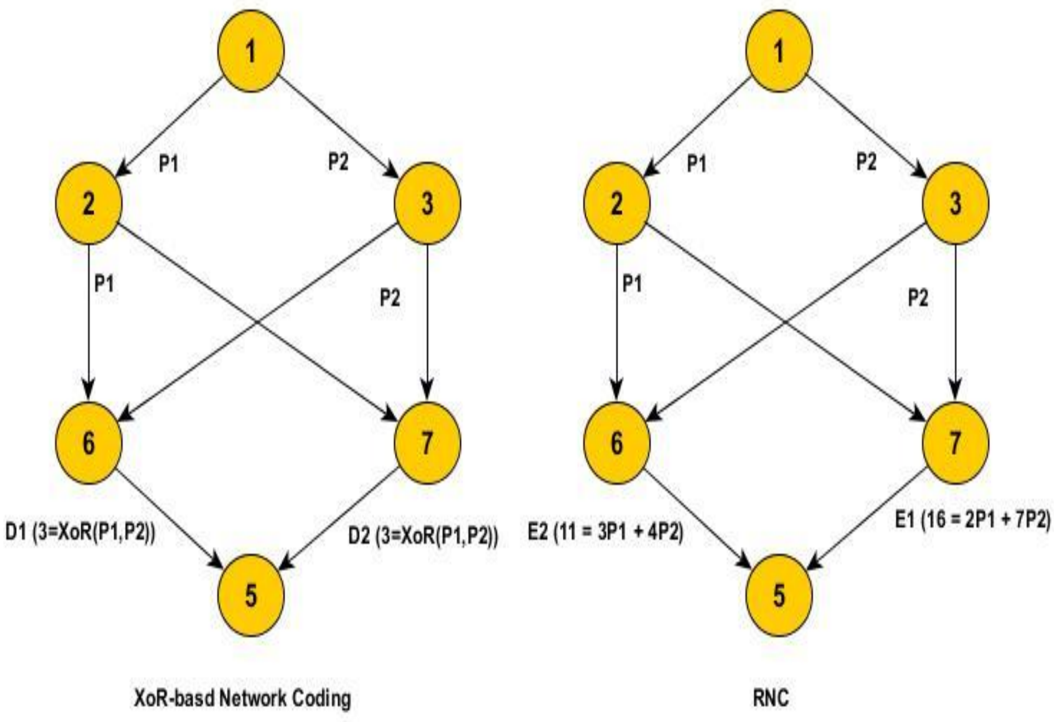

Figure 1.2 RNC Addresses the Content Reconciliation Problem

What can be inferred is that RNC needs to generate some coefficients entries in encoding process and can easily decode encoded blocks if it receives these coefficients correctly. This is why peers 6 and 7 have to attach generated coefficients entries to the encoded blocks E1 and E2, respectively, before sending them to peer 5.

Generally, the video source divides the video stream into many fixed-size segments, each of them further divides into *n* *k*-byte blocks. These block are arranged in matrix $B_{n\times k}$. Then, the RNC-Encoder select n^2 random values in GF(2^m) (Galois Field) and arranges them in coefficients matrix $C_{n\times n}$. The *m* is an integral value which is set to 8 in computer communication. Finally, the encoded matrix $X_{n\times k}$ which includes *n* *k*-byte encoded block can be generated by multiplying matrix $C_{n\times n}$ by $B_{n\times k}$ (Wang and Li, 2007b). The video source attaches *n*-byte coefficients vector (*n* coefficients entries) to each *k*-byte encoded block in the form of one or more packets before transmitting it to the next hop. Encoding process can be performed by each intermediate node on the path toward the destination.

The destination node decodes video blocks as soon as it receives *n* linearly independent encoded blocks by RNC-Decoder. Since 2006, RNC-Decoders have used the Gauss-Jordan elimination method (Hoffman and Kunze, 1971) in the decoding process. This method progressively performs decoding process as soon as the first encoded block receives. Successfully decoding of all *n* encoded blocks is impossible if the RNC-Decoder finds that there is a linear dependency between two received coefficient vectors (Mirshokraie and Hefeeda, 2010).

Considering the RNC operation in encoding and decoding processes, there are three open issues in RNC which considerably affect its performance, especially in live video streaming (Wang and Baochun, 2007; Mirshokraie and Hefeeda, 2010; Peng *et al.*, 2014) as follows:

i. High transmission overhead due to attaching large coefficients vectors as a header. High transmission overhead increases the transmission queue delay and wastes the limited available bandwidth of peers, because they cannot efficiently assign their upload bandwidth for transferring video blocks.

ii. Excessive decoding computational complexities due to using the Gauss-Jordan elimination method (Lee *et al.*, 2012; Qureshi *et al.*, 2012). The fact is that this complexity is not suitable for wireless nodes with low computation power (e.g. Smartphones and iPods) (Keller *et al.*, 2012),

iii. Linear dependency among the coefficients vectors can degrade the number of innovative video blocks in receivers which can reduce the video quality (Qureshi *et al.*, 2012).

Albeit RNC increases video quality, employing inefficient routing protocol can degrade the video quality in hybrid WMNs. In other words, time-varying channels, intra- and inter-interferences, long distance between source and destination in terms of the hop count and node mobility are some important challenges in WMNs which can reduce the perceived video quality (Kumar, 2012; Wei *et al.*, 2012). These challenges can reduce the positive effects of using an efficient streaming method.

Proactive and reactive are two important routing protocol classifications in WMNs (Akyildiz and Wang, 2009). However, low scalability with large networks, high network overhead, large amount of data for maintenance when there are mobile nodes in a hybrid WMN and slow reaction in case of path failure are the most important challenges of proactive protocols (Kumar, 2012; Reddy *et al.*, 2013; Sahingoz, 2013), while reactive protocols suffer from high latency and network overhead when they are employed in the backbone of a WMN (Rishiwal *et al.*, 2008; AlAamri *et al.*, 2013; Dhenakaran and Parvathavarthini, 2013). Moreover, based on these studies, reactive protocols imposes high network overhead and latency for finding paths in a dynamic network, but lesser than that of proactive protocols.

In this regard, a hybrid protocol, which is an intelligent and efficient integration of these two routing protocols, can efficiently address their open issues (Abolhasan *et al.*, 2004; Kaur and Kumar, 2012). This hybrid routing protocol should efficiently support STA nodes. Proactive and reactive protocols cannot efficiently support them, because the first uses routing tables for keep their locations, while the second one exchanges many RREQ and RREP messages for locating a path to STA nodes. This sharply increases routing and network overhead. Hence, employing an efficient locator service is necessary for locating STA nodes (Mase, 2011). A routing protocol should be efficiently designed in which it can exploit the advantages of this locator.

Moreover, implementation of the proposed hybrid routing protocol in the IP layer introduces some new challenges. Auto-configuration problem due to using protocol (DHCP) server (RFC791, 1981), inconsistency in routing table when two independent routing protocols are active in IP layer, large required storage for routing tables and high routing overhead are the most important challenges to name a few. Access points (APs) and STA nodes are not able to decode IP packets in the link layer. In fact, adding required functionalities in the IP layer to these nodes imposes very high cost.

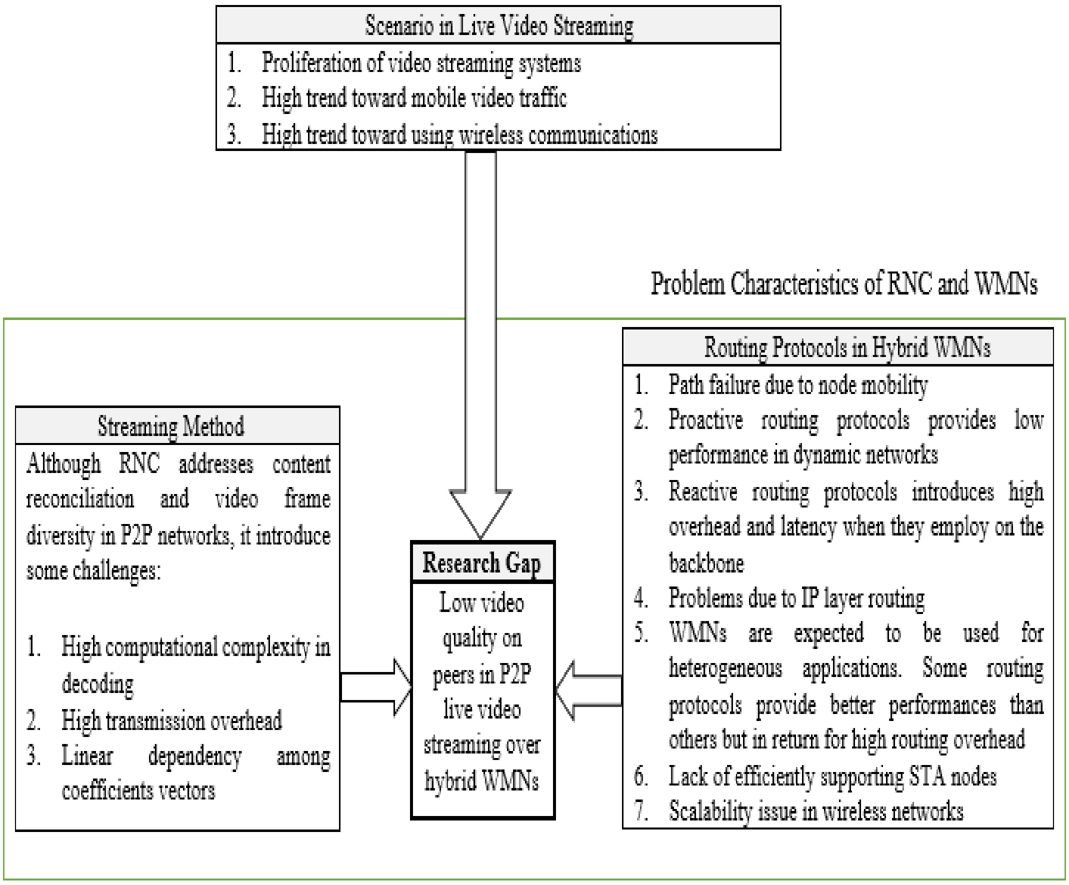

Figure 1.3 Scenarios Leading to the Research Gap Identification

On the other hand, link layer routing not only addresses the mentioned challenges, but it also provide quick routing and hides the network complexity from upper layers (Faccin *et al.*, 2006). Therefore, it is better to implement the hybrid routing protocol in the link instead of the IP layer this. Figure 1.3 summarizes considered research gaps by this study. Altogether, providing smooth video playback on peers in a hybrid WMN needs efficient video streaming method and routing protocol. In other words, by addressing existing challenges in random network coding and routing protocols in hybrid wireless mesh networks, smooth video playback can be provided on peers in a P2P live video streaming system over hybrid WMNs.

1.3 The Problem Statement

What can be inferred from Section 1.2 is that an efficient scheme not only has to exploit the advantages of the H.264/MPEG-4 standard and mesh-based P2P overlay networks, but it also needs to address existing open issues in RNC and routing protocols in WMNs. Recent studies such as the performed works by Anh *et al.* (2010), Wang *et al.* (2011) and Xingjun *et al.* (2012) show that RNC improves the perceived video quality on peers by addressing the content reconciliation problem in P2P networks and increasing the network throughput. Inefficient routing protocols in WMNs can noticeably affect the performance of RNC. In this regard, an efficient routing protocol which considers node mobility, stable paths, churning and interferences is needed. These problems are more visible when a delay sensitive stream such as a live video is propagating over the WMN. As a result, the big question is:

"*How would a live video streaming scheme efficiently increase the perceived video quality on peers in P2P live video streaming over hybrid WMNs by integrating a novel coefficients matrix generation/inversion method and an enhanced hybrid routing protocol in random network coding and hybrid wireless mesh networks, respectively*?"

A suitable solution should answer the following sub-questions in random network coding:

i. What is the appropriate coefficients matrix generation method in which it addresses transmission overhead issue in RNC in which better video quality can be provided on peers?
ii. What is the appropriate coefficients matrix inversion method in which it addresses computational complexity issue in matrix inversion process due to using the Gauss-Jordan elimination method in RNC?
iii. What is the appropriate coefficients matrix generation method in which it addresses computational complexity and non-innovative video block issues due to checking and existing linear dependency in RNC, respectively?

This solution also needs to answer these sub-questions in a hybrid wireless mesh network:

i. How a hybrid routing protocol can efficiently exploit the advantages of proactive and reactive schemes, while it addresses their challenges?
ii. How this hybrid routing protocol efficiently considers important issues in hybrid WMNs such as time-varying channels, node mobility, interferences and churning for providing smooth video playback on mesh/STA nodes?
iii. How this hybrid routing protocol can efficiently exploit the advantages of a STA locator service for efficiently supporting them in a hybrid WMN?
iv. How this hybrid routing protocol can efficiently reduce the imposed routing overhead, end-to-end delay and packet delay variation?

Finally, the following sub-question can be answered by the proposed scheme by this research:

i. How to design a live video streaming scheme by integrating the introduced solutions for providing smooth video playback in P2P live video streaming over hybrid WMNs? This scheme should reduce video distortion, frame dependency distortion, initial start-up and end-to-end delays.

1.4 Purpose of the Research

The purpose of this research is to design a live video streaming scheme for efficient peer-to-peer live video streaming over hybrid wireless mesh networks in which it can provide high video quality on peers by introducing an efficient coefficients matrix generation/inversion method in RNC and hybrid routing protocol in hybrid WMNs.

1.5 Objectives of the Research

The main goal of the proposed scheme by this study is to provide high video quality on peers in a P2P overlay over a hybrid wireless mesh network.

Therefore, considering the background and the problem statement sections as well as the purpose of this research, three main objectives of this research can be propounded as follows:

i. To reduce the imposed decoding computational complexity and transmission overhead by RNC using a novel coefficients matrix generation and inversion method such that no linear dependency exists among the coefficients vectors,
ii. To finds the most stable path by proposing an enhanced hybrid routing protocol in hybrid WMNs which efficiently considers node mobility and exploits the advantages of a STA locator service,
iii. To provide high video quality by integrating the first two objectives in form of a scheme and show how it can provide smooth video playback in P2P live video streaming over hybrid WMNs.

1.6 Scope of the Research

Based on the previous sections, in this research:

i. Real live video trace file based on the H.264/MPEG-4 standard from (Arizona, 2009) is disseminated from a live video source to all peers,
ii. A hybrid wireless mesh network is established as the underlying network using INETMANET frameworks in OMNET++ (OMNET++, 2010). Then, a mesh-based P2P overlay network is constructed over the underlying network using OVERSIM framework,
iii. RNC is selected as an efficient streaming method for live video streaming in the constructed overlay. The video stream divides into some segments, each of them further divides into *n* *k*-byte blocks before encoding by the RNC method,
iv. A hybrid routing protocol, which is an intelligent integration of proactive and reactive schemes, routes frames among wireless mesh/STA nodes and mesh routers.

1.7 Research Phases

Chapter 3 explains the research phases in detail. In this section, Figure 1.4 briefly depicts the considered phases of the proposed scheme. The first and the second objective exist in the first and the second phase, respectively. The first phase deals with the encoding/decoding process using RNC.

In fact, the live video stream is divided into some fix-sized video segment, each of them is future divided into some fix-sized blocks. Then, RNC employs the EMGIM method for generating the required coefficients matrix before starts to encoding these blocks. RNC-Encoder generates the coefficients matrix without any linear dependency among its vectors. Moreover, very low transmission overhead can be imposed on the network due to attaching very small header (one byte) to the encoded blocks as coefficient entry.

PHASE 1
EMGIM: A novel and **E**fficient coefficients **M**atrix **G**eneration and **I**nversion **M**ethod in random network coding with very low computation complexity and transmission overhead.
PHASE 2
GREENIE: A **G**ood hybrid **R**outing protocol in which it **E**fficiently and **E**ffectively routes packets in a hybrid wireless mesh **N**etwork and **I**ntelligently **E**mploys proactive and reactive routing protocols based on the node mobility.
PHASE 3
GAZELLE: It is **G**enerated based on **A Z**onate vision for **E**fficient peer-to-peer **L**ive video streaming over hybrid wireless mesh network with **L**ow video distortion, frame dependency distortion, initial start-up delay, end-to-end delay and high network throughput among **E**nd-users. Actually, it is an integration of EMGIM and GREENIE for efficient peer-to-peer live video streaming over hybrid wireless mesh networks.

Figure 1.4 Research Phases

Finally, very low decoding computational complexity is imposed on RNC-Decoder using efficient matrix inversion method in EMGIM. In this regard, RNC can be more applicable for running on small gadgets such as Smartphones.

As soon as RNC generates the encoded blocks, it sends them to the second phase in order to deliver them to the final destination using GREENIE routing protocol. GREENIE efficiently routes these encoded blocks in figure of some link-layer frames. This hybrid routing protocol, which is based on proactive and reactive protocols, always look for the most stable path between source and destination. This path consists of more number of fixed nodes.

Moreover, it efficiently route frames to STA nodes as soon as it finds the lactation of it. In this sense, it can exploit the advantages of having a locator more than other routing protocols, because there is no need to keep the addresses of STA nodes in proactive tables or send many RREQ/RREP messages in reactive protocol. As a result, routing overhead can be sharply reduced. In the rest of this thesis, EMGIM and GREENIE are given names to the first and the second phase of this research scheme, respectively.

Finally, GAZELLE, the proposed scheme for efficient peer-to-peer live video streaming among end-users in a hybrid wireless mesh network, is considered as the third phase of the research. GAZELLE is an integration of EMGIM and GREENIE. By exploiting the advantages provided by the first two phases, GAZELLE not only provide efficient streaming method among peers, but it also effectively route generated encoded video blocks by the first phase in the second phase.

1.8 Contributions of the Research

This research addresses the existing issues in RNC in the following manner. Therefore, all nodes, especially, gadgets such as Smartphones, can better exploit the advantages of employing RNC for video streaming.

i. Gadgets (e.g. Smartphones) with low CPU processing power can easily exploit the advantages of RNC using low battery energy sources, because EMGIM sharply reduces the imposed decoding computational complexity on them. Therefore, these nodes can save their battery energy resources for other running application on them,

ii. The necessity of checking any linear dependency in the generated coefficients matrix in RNC can be completely removed if RNC uses the EMGIM's rules in coefficients matrix generation step. This increases the number of innovative video blocks in the network which results in less amount of video distortion. Therefore, better video quality can be provided,

iii. The imposed transmission overhead due to attaching large coefficients vector to the encoded block in RNC can be sharply reduced, because just one instead of *n* bytes is attached as header to encoded block. This decreases the packet length. Therefore, more number of video blocks can be embedded in a packet which results in fewer number of transmission and less interferences in WMNs. Network throughput can be also increased. Better video quality is the final result of these advantages. In summary, better video quality can be provided in a wireless network by addressing transmission overhead issue in RNC.

Moreover, in order to increase the perceived video quality on receivers in WMNs, this study proposes an enhanced hybrid routing protocol in which,

i. Node mobility is efficiently considered in the designed hybrid routing protocol, GREENIE. In fact, the backbone of the MR is restricted to using proactive, while mobile nodes use reactive routing protocol. Therefore, the required path from a source to a destination can be established in a shorter time. This increases the network throughput while routing overhead can be sharply reduced. Nodes experience better video quality using GREENIE,
ii. GREENIE, in the second phase, finds the most stable path which consists of more number of fixed nodes. Hence, the amounts of video distortion, end-to-end delay and packet delay variation can be reduced in comparison with current routing protocols in hybrid WMNs. This results in better video quality on STA and mesh nodes, because more number of video frames can be delivered to them. In other words, network throughput can be improved. Based on this fact that GREENIE is implemented in the link instead f the IP layer, it is possible to have two independent proactive and reactive tables without any inconsistency between them. GREENIE first searches for a valid path in the proactive cache which results in finding the most stable path between a source and a destination,
iii. STA nodes can be efficiently supported, because GREENIE can exploit the advantages of this locator more than other routing protocols.

Actually, GREENIE efficiently finds the route to a STA node as soon as the locator helps it to find the location of it.

Finally, efficient peer-to-peer live video streaming over hybrid wireless mesh networks can be provided using an integration of these methods in the form of a live video streaming scheme, named GAZELLE. GAZELLE exploits the advantages provided by EMGIM and GREENIE for providing high video quality on receivers. The fact is that the performance of RNC can be considerably affected by an inefficient routing protocol in the underlying network.

As a result, integration of the proposed coefficients matrix generation method in RNC and enhanced hybrid routing protocol in WMNs in form of a scheme can considerably increase the perceived video quality on receivers.

1.9 Significance of the Research

The research is significant and important from theoretical and practical perspectives. For example, high video quality on peers can be the most important issue when a lecturer is delivering a live speech to some students' gadgets on campus. It is generally believed that live video streams have been one of the most important traffics over all computer networks, especially the Internet and wireless networks. The fact is that many people are eager to watch live or on-demand video streams using their gadgets (Saeed *et al.*, 2013). Therefore, P2P video streaming over wireless mesh networks using random network coding has been of great interest for this purpose (Zhenyu *et al.*, 2011).

However, existing challenges such as transmission overhead and computational complexity in random network coding and competitions, interferences, node mobility and collisions in WMNs can lead to low video quality on peers. The key point is that providing smooth video playback on peers is completely dependent on employing a scheme in which it precisely considers both the employed streaming method and routing protocol in the network.

1.10 Organization of the Thesis

In this chapter, four important issues in providing smooth video playback on peers in P2P live video streaming over hybrid WMNs including efficient video compression standard, network communication approach, streaming method, and reliable wireless infrastructure are discussed. Based on the third and the fourth issues, it is necessary to address existing challenges in RNC and hybrid WMNs for providing better video quality on peers.

In chapter 2, literature review on previous related works on P2P video streaming over mesh-based networks with focus on using network coding in live video streaming is provided. In chapter 3, the research methodology is discussed in detail. Chapter 4 describes EMGIM which is the first objective of this research. Chapter 5 discusses on GREENIE, the proposed hybrid routing protocol in WMN. Chapter 6 discusses on the proposed scheme by this study, GAZELLE. Finally, this research is concluded and summarized in chapter 7.

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