GENETIC ALGORITHM BASED NETWORK CODING IN WIRELESS AD HOC NETWORKS

TAN SHEE ENG

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PK2010-8100

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NAME : **TAN SHEE ENG**

MATRIC NO. : **PK2010-8100**

TITLE : **GENETIC ALGORITHM BASED NETWORK CODING IN WIRELESS AD HOC NETWORKS**

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DECLARED BY

1. **SUPERVISOR**
   Mr. Kenneth Teo Tze Kin — Signature

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ABSTRACT

GENETIC ALGORITHM BASED NETWORK CODING IN WIRELESS AD HOC NETWORKS

The main objective of this research is to maximize the throughput and minimize the energy consumption in wireless ad hoc networks with network coding by selecting a suitable route to destination. Packet's forwarding of the conventional store-and-forward in an intermediate node is just storing the received packets and then forwarding the same packet without doing any additional processing to the packets. In the intermediate node of network coding (NC), instead of store then forward data packets, the nodes in NC can perform additional function by encoding several packets into a single coded packet, and then transmit the coded packet to respective destinations simultaneously. Wireless network simulation is used to demonstrate and assess the implementation of network coding in wireless ad hoc networks. Every destination node will decode the coded packet to get the intended packet. Results show that the network coding transfers the packets 13.64% faster than store-and-forward method. However, the chances to perform network coding in wireless ad hoc networks are limited if the path of packet does not flow through potential network coding nodes. Therefore, coding-aware routing is important to explore the data traffic flows with more network coding opportunities. Genetic algorithm based coding-aware routing (GACAR) is embedded in the wireless ad hoc network with network coding capabilities to search for coding opportunities for unicast sessions. In this work, an adaptive genetic algorithm based coding-aware routing (AGACAR) is also proposed to improve the solution on the GACAR. Evaluation and assessments have been carried out through various simulations under different network topologies, and it shows that AGACAR provides better coding opportunities and reduces energy consumption in the network. The expected transmissions count metric (ETX) for AGACAR is 22.27% fewer than store-and-forward and 16.33% fewer than network coding in wireless network transmission and forwarding structure (COPE).

ABSTRAK

Objektif utama kajian ini adalah untuk memaksimumkan daya pemprosesan dan mengurangkan penggunaan tenaga dalam rangkaian ad hoc tanpa wayar dengan "network coding" (NC) dengan memilih laluan yang sesuai ke destinasi. Paket penghantaran konvensional simpan-dan-hantar dalam nod perantaraan hanya sekadar menyimpan paket yang diterima dan kemudian memghantar paket yang sama tanpa melakukan apa-apa proses tambahan kepada paket. Simulasi rangkaian tanpa wayar diwujudkan untuk mengaji NC dalam rangkaian ad hoc tanpa wayar. ia bukannya sekadar paket data simpan-dan-hantar tetapi nod dalam NC boleh membuat proses tambahan dengan beberapa paket dikodkan ke dalam satu paket kod tunggal, dan paket berkod dihantar ke destinasi seterusnya. Setiap nod destinasi akan dinyahkod paket berkod untuk mendapatkan paket asal. Hasil kajian menunjukkan bahawa rangkaian kod menhantar paket 13,64% lebih cepat daripada simpan-dan-hantar. Walau bagaimanapun, peluang untuk melaksanakan rangkaian kod dalam rangkaian ad hoc tanpa wayar adalah terhad jika jalan aliran trafik data tidak mengalir melalui ke nod kod yang berpotensi. Oleh itu, laluan kod sedar adalah penting untuk meneroka aliran trafik data dengan lebih banyak peluang NC. Algoritma genetik berdasarkan kod sedar laluan (GACAR) terbenam dalam rangkaian ad hoc tanpa wayar dengan rangkaian kod keupayaan dapat mencari data laluan trafik yang lebih baik untuk sesi unicast. Dalam kajian ini, peningkatan GACAR (AGACAR) juga dicadangkan untuk memperbaiki penyelesaian bagi GACAR. Penilaian telah dijalankan melalui simulasi di bawah rangkaian topologi berbeza yang menunjukkan bahawa peningkatan AGACAR menyediakan peluang pengkodan yang lebih baik dan mengurangkan penggunaan tenaga. Penghantaran dijangka mengira metrik (ETX) untuk AGACAR adalah 22.27% kurang daripada simpan-dan-hantar serta 16.33% kurang daripada rangkaian kod dalam penghantaran rangkaian wayarles dan struktur penghantaran (COPE).

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LIST OF ABBREVIATIONS

AI	Artificial Intelligent
ANCHOR	Active NC high-throughput optimizing routing
AODV	Ad Hoc On Demand Distance Vector Routing
CAR	Coding-Aware Routing
COPE	Network Coding in Wireless Network Transmission and Forwarding Structure
CRM	Coding-Aware Routing Metric
CTS	Clear-to-Send
DCAR	Distributed Coding-Aware Routing
EA	Evolutionary Algorithm
ECX	Expected Number of Coded Transmissions
ER	Efficient retransmission
ETX	Expected Transmissions Count Metric
GA	Genetic Algoritm
GACAR	Genetic Algorithm Based Coding-Aware Routing
GCAR	Genetic Algorithm Based Coding-Aware Routing In Wireless Mesh Network
ID	Identity
LPF	Linear Programming Based Formulations
NC	Network Coding
NCAR	Network Coding Aware Routing
NCP	Network Coding Problem
NCQEA	Network Coding For Quantum-Inspired Evolutionary Algorithm
NJCAR	Network Joint Coding-Aware Routing
noCoCo	Near-Optimal Co-Ordinated Coding

QEA	Quantum-Inspired Evolutionary Algorithm
OSI	Open Systems Interconnection
ROCX	Opportunistically Coded Exchanges
RREP	Route Reply
RREQ	Route Request
RTS	Request-to-Send

LIST OF SYMBOLS

ΔBS	Best solution that continual appearance
$\lvert F_i \rvert$	Magnitude of vector i
$\lvert F_d \rvert$	Magnitude of vector destination
α	weighting factor of crossover
$\alpha_{ei,ej}$	Packet flow from source to next link
$\beta_{ei,ej}$	Packet flow from intermediate node's link to next node's link
$c_{k,i,j}$	Amount of traffic between k and i through intermediate node j
$\varepsilon_{ei,ej}$	Packet flow from intermediate node's link to destination node's link
η^+	Best individual
η^-	Worst individual
θ_{ji}	Angle between node i and j
e_i	Link i
Eu	Euclidean distance
E_{Tx}	Transmission energy
E_{Rx}	Receiving energy
ETX_{wnc}	Expected transmissions count metric with network coding
ETX_{wonc}	Expected transmissions count metric without network coding
F_d	Vector node destination
F_{d_x}	Position vector x for node destination
F_{d_y}	Position vector y for node destination
F_i	Vector node i
F_{i_x}	Position vector x for node i
F_{i_y}	Position vector y for node i

F_x	Position vector x
F_y	Position vector y
$F(z)$	Fitness function of genetic algorithm based coding-aware routing
G_k	Number of current generation
G_{max}	Maximum generation
i	Number of node
j	Number of node
k	Total bits of packet
k_{ji}	Connection between node i and j
l	Ranking of chromosome
m_d	mutation rate
m_{max}	Maximum mutation rate
$MIQ(l)$	Modified interference queue
n	Number of node
N	Total of chromosome
p_i	Probability of link i
$p_{i_{new}}$	New probability of the link i
$p_{i_{old}}$	previous probability of the link i
p_l	Linear selection probability
P_{link}	Packet loss probability
p_{max}	Maximum of probability of the link
R	Regenerate quantity
R_{max}	Maximum quantity of regenerate chromosome
$r_{i,j}$	probability of two-way successful transmission between i and j

T	Trigger value to regenerate
x	Node x-axis position
$x_{i,j}$	Link quantity require between i and j
y	Node y-axis position

CHAPTER 1

INTRODUCTION

1.1 Wireless Networks

Wireless technology for data transmission is introduced since World War II. Instead of being a tool for destruction during the war, wireless technologies today increase the human productivity and simplify the daily work. Wireless networks are widely used in industries and at home due to the mobility, wide signal coverage, robustness, reliable connectivity, easily deployed at low cost without relying on the existing infrastructure. Different names have been specified for wireless networks according to their application types, such as wireless mesh networks, wireless sensor networks, vehicular networks, and mobile ad hoc networks (Akyildiz *et al.,* 2002; Akyildiz and Xudong, 2005; Hartenstein and Laberteaux, 2008; Tracy *et al.,* 2002).

In general, a wireless network has multiple wireless nodes to form a network. Every node in a wireless network will communicate with each other by transmitting packets between the nodes. A source node is referring to a starting point for the information packet to be transmitted whereas the destination node is the end point to receive the information packet. In the wireless network, if source node and destination node are too far away from each other, the information packet will be transmitted to intermediate node(s) before forwarding to the destination. The communications protocols between the nodes are standardised by open system interconnection (OSI), which is a conceptual model of communication. In the physical layers of OSI model, a set of physical layer standard which is known as IEEE 802.11 standard is used to standardise the communication frequency band of wireless networks. In the conventional wireless network, merely receive, transmit, and forward information is referred to as store-and-forward method, where no additional information processing happens at the intermediate nodes. The throughput provided by conventional wireless networks using store-and-forward method is limited. The throughput means the successful information transmitted through a second, with the unit bit per second (bps). Therefore, a new protocol to improve the throughput of the conventional store-and-forward method is introduced, which is network coding (NC) (Ahlswede *et al.,* 2000). Unlike store-and-forward, NC can process the information packet in the intermediate node before forwarding the packet to the destination node.

1.2 Routing in Wireless Ad Hoc Networks

In wireless ad hoc networks, every wireless node will transmit the packet to intermediate nodes if the packet cannot be directly transmitted to the destination. During receiving, the node will store the packet in a buffer (which acts as storage) before the packet is forwarded to the next hop. If the node is receiving more than transmitting, the packet quantity on the buffer will slowly increase. The conventional store-and-forward queues up and transmits the packet one by one until all packets in the buffer are transmitted. On the contrary, NC allows each node on the network to combine multiple packets before forwarding them. In other words, NC allows the buffer to queue multiple packets in a transmission.

For NC to take place in the wireless networks, the NC opportunities, whether a packet is transmitted with or without NC, is determined by the buffer's queue state at a given node (Wei *et al.,* 2007). The improvement on the buffer's queue state handling at a given node will be discussed in Chapter 3. Besides the buffer queue state, the instantaneous link conditions between nodes could also affect the chances of NC to happen. Hiroyuki and Peter (2007) tried to improve the NC by opportunistic scheduling the packets for transmission according to the on-the-spot link conditions. Moreover, apart from improving NC locally, NC opportunities can be increased by controlling the flow of the packet (i.e. routing) in terms of global view on the networks, which is controlling the flow of packet by considering the conditions of multiple nodes (Bin *et al.,* 2006; Sengupta *et al.,* 2007; Wei *et al.,* 2009).

Routing is important in NC as a selecting packet path across a network. Conventional routing protocols for wireless networks usually find the shortest path from the source to the destination nodes (Perkins and Royer, 1999). However, the existing of NC changes the conventional way of communication in a wireless network. The shortest path toward the destination is not longer the best way to route packets to destination because NC can reduce the number of transmissions required to deliver the packet to the destination. Some other longer paths may provide more coding opportunities that reduce transmissions while delivering packets. Therefore, routing protocol is important to adapt the NC in order to utilise the potential of NC in wireless networks.

The optimum path to transfer packet from the source to the destination helps improving the wireless NC networks, which is known as route discovery. Minkyu *et al.* (2007a) and Huanlai *et al.* (2008) proposed to use evolutionary approaches to search for the optimal packet transmission path in multicast wireless NC networks. There are two types of routing in wireless ad hoc networks, depending on the application, which are multicast and unicast. Multicast is the flow that transfers packets from a source to multiple destinations whereas unicast is transferring packets from a source to a destination. Apart from multicast, Xing *et al.* (2012) proposed to use genetic algorithm (GA) to search for the packet flow in unicast wireless NC networks. GA is a type of optimization technique that based on Darwin's biological evolution process (Kenneth, 2006). GA can iteratively search for optimal path that has more coding opportunities.

This thesis focuses on utilizing NC in the wireless ad hoc network by using GA to search for packet path for the unicast case. Searching the path for unicast packet in wireless NC networks with the awareness of NC is also called as coding-aware routing (CAR). GA proposed path searching for the packet in unicast case, which is developed for this work, is termed as genetic algorithm based coding aware routing (GACAR). GACAR is used to optimize the path of the packet and to increase the throughput of the wireless networks. It is challenging to define the proper parameter values for the solution of GACAR from being trapped at local optimum. To improve the solution of the GACAR, Adaptive GACAR (AGACAR) which considers the selection pressure of the link, the mutation rate, and the reselection rate to control the trade-off balance of exploration and exploitation, will be furthered discussed in Chapter 6.