Variable Length Sliding Window-based Network Coding Algorithm in MANETs*

Chao Gui
School of Information and Engineering,
Hubei University of Economics
Wuhan 430205, China
gui_chao@126.com

Baolin Sun
School of Information and Engineering,
Hubei University of Economics
Wuhan 430205, China
blsun@163.com

Ying Song
School of Information and Engineering,
Hubei University of Economics
Wuhan 430205, China
prisong@163.com

Kun Xiao
School of Information and Engineering,
Hubei University of Economics
Wuhan 430205, China
xiaokun0304@sina.com.cn

Chengli Huang
Computer Engineering Department,
Guangdong Youth Vocational College
Guangzhou 510507, China
chengli_huang@163.com

ABSTRACT

Network coding (NC) consists of intelligently aggregating data packets by means of binary or linear combinations. NC has been considered as one of the possible solutions to the current low throughput, energy consumption, packet loss, non-connectivity and mobility support problems in MANETs. Sliding-window Network Coding is a variation of NC that is an addition to TCP/IP and improves the throughput of TCP on wireless networks. In this paper, we propose a Variable Length Sliding Window-based Network Coding algorithm in MANETs (VLSW-NC). The performance of this VLSW-NC is studied using NS2 and evaluated in terms of the throughput, packet loss probability, and decoding delay when packet is transmitted. The simulations results shows that the VLSW-NC achieved with our proposition can significantly improve the network performance and reliability.

CCS CONCEPTS

• **Networks** →Ad hoc networks; Mobile ad hoc networks

KEYWORDS

MANET; variable length sliding window; network coding

ACM Reference format:

C. Gui, B. L. Sun, Y. Song, K. Xiao, and C. Huang. 2017. Variable Length Sliding Window-based Network Coding Algorithm in MANETs. In *Proceedings of MobiQuitous 2017, November 7-10, 2017, Melbourne, VIC, Australia*, 6 pages.
DOI: 10.1145/3144457.3152354

1 INTRODUCTION

Mobile Ad hoc NETworks (MANETs) consist of a large number of mobile nodes which are randomly deployed with mobility, computation, and communication capabilities. The MANET is a multi-hop self-organizing network system. When one node moves out of or into the transmission range of another node, the wireless link between the two becomes down or up [1–3]. Although, MANET has its limitations, such as mobile node's energy, communication link, computing and storage capacity are very limited and so on. How to improve network energy efficiency and decrease network energy consumption is still a main challenge.

Network coding (NC) was originally proposed to increase the capacity of one-to-many communication like multicast communication [4]. Recently, it is also expected that network coding can improve the capacity of multihop wireless networks in which a wireless node encodes several input packets into one or multiple packets and broadcasts encoded packets to neighboring nodes.

Ahlswede et al. [4] considered network coding for solving energy consumption in multi-hop wireless networks. But they did not give a specific network coding implementation. Network coding is not new, it has its foundation in different systems which were highlighted by Yeung [5] while discussing the historical perspective of network coding, that lead to the seminal paper on network coding. Jaggi *et al.* [6] gave deterministic polynomial time algorithms and even faster randomized algorithms for designing linear codes for directed acyclic graphs with edges of unit capacity. Aktas *et al.* [7] propose a simple yet effective wireless network coding and decoding technique for a multiple unicast network. Kagi et al. [8] proposed an efficient and reliable packet transmission algorithm by using multipath routing

---

*Produces the permission block, and copyright information
[†]The full version of the author's guide is available as acmart.pdf document
[1]It is a datatype.

MobiQuitous 2017, November 7-10, 2017, Melbourne, VIC, Australia

DOI: 10.1145/3144457.3152354}

constructs from multiple node disjoint routes, and by applying network coding which allows packet encoding at a relay node.

Under the traditional block coding approach, the delivery rate of these receivers would be zero. Using deterministic network coding, however, it may be possible for the receivers to continue decoding new information, despite never being able to fully receive all information that has so far been transmitted by the sender. The NC challenges arise when attempting to simultaneously achieve fast coding, low complexity, high data transmission rates, small buffer and adaptation to the unknown channel conditions. Of these challenges, fast coding, compulsory reliability and real time constraint are specific to energy efficient network coding for multi-hop routing in MANETs.

This paper proposes to use a Variable Length Sliding Window-based Network Coding Algorithm in MANETs (VLSW-NC). The packets at source nodes are transmitted on the MANETs. Then, intermediate nodes encode the received packets and forward the new packets to next node. Finally, the destination node decodes the packets received from different paths and recovers the original data. The performance of this VLSW-NC is studied using NS2 and evaluated in terms of the throughput, packet loss probability, and decoding delay when packet is transmitted.

The rest of the paper is organized as follows. Section 2 discusses the some related work. Section 3 describes a Variable length sliding window algorithm in MANET. Section 4 introduces network coding mechanism in MANET. Some simulating results are provided in section 5. Finally, the paper concludes in section 6.

2 RELATED WORKS

Network coding has been studied to combat performance loss due to poor link quality. The works in [8–9] apply network coding to increase network throughput by using opportunistic routing in the face of loss wireless links. Kwon *et al*. [9] propose a mode-based algorithm for approximate decoding, where the mode of the source data distribution is used to reconstruct source data. The work in [10] analyzes the rate and BER performance when applying PNC (Physical layer Network Coding) in two-way relay channel. We consider PNC in this paper, since PNC does not require strict synchronization at the physical layer, which is simpler to implement. The works in [11] analyze the theoretical throughput gain provided by network coding. The work in [12] considers the coding-aware routing problem in multi-hop wireless networks. Linear programming is used to develop a theoretical formulation. On the other hand, is to develop a practical distributed routing protocol for identifying high throughput paths. The routing metric proposed by [13] uses the buffer length to reflect how busy the node is, and a path with the minimum aggregate buffer length is selected. Coding opportunities are considered when calculating the buffer length at each node.

Chen *et al*. [14] presented a sliding-window method to construct cyclic and quasi-cyclic structured *q*-ary LDPC codes over small fields. The construction is performed with a pre-defined sliding-window, which actually executes the regular mapping from original field to the targeted field under certain parameters. Qu *et al*. [15] propose a delay controlled network coding (DCNC) protocol, which can improve the throughput for real-time traffic by dynamically controlling the delay in wireless mesh networks. The authors build up a delay prediction model to capture the relationship between the average packet delay and the encoding batch size. In [16], the instant decodable network coding is generalized so that hard delay constraint for each packet could be satisfied, but their schemes are optimal only when there are no more than three receivers.

NC can be used as a backward-compatible enhancement to TCP in order to improve efficiency in loss networks such as wireless networks. In [17], two implementations of a new algorithm are proposed in order to decrease the total transmission time, and to increase the decoding throughput the transmission (TCP/NC). In TCP/NC, redundancy is used preemptively against packet losses: instead of resending packets after losses have been detected, the number of transmitted packets *t* is multiplied by a redundancy factor *R*, ensuring that enough packets are transmitted so that *t* packets arrive at their destination. Chen *et al*. [18] introduce compressed sensing (CS) into NC scheme and construct a cooperating coding mechanism, which performs over different data fields with a compatible transformation measure for the combination of NC and CS. Zeng *et al*. [19] proposed a dynamic segmented network coding scheme to apply network coding into the Delay/Disruption Tolerant Network (DTN). Khamfroush *et al*. [20] investigated the optimal use of Network Coding for a multicast scenario that allows for cooperation between destinations to reduce the cost of multicast packet transmission.

In [21], a cooperative multicast protocol named MWNCast is proposed based on the moving window network coding (MWNC) technique. The MWNCast scheme can effectively alleviate the bottleneck problem in wireless multicast. Lim *et al*. [22] propose an efficient sliding window algorithm employing a variable-length guard window which results in average guard window lengths significantly smaller compared to the guard window length of the conventional sliding window algorithm using fixed-length guard windows.

To deal with this issue, a sliding window network coding-based approach is conducted in this work, along with the analysis of a variety of performance indicators, including popular indicators used by investors and statistical measurements. New changes in the economic scenario can be identified by recent training phases. The use of sliding windows makes it possible to find recent frequent patterns in data streams.

3 VARIABLE LENGTH SLIDING WINDOW

Variable length sliding window can adaptively adjust the sliding window size according to the change of data packet stream and data packet distribution in order to achieve a minimum consumption of memory space, coding window, decoding window, and processing time.

The Variable length sliding window is, the more redundant information that window contains, and then the better suppression effect of the decoding error has. However, when the mobile node moves faster, then the longer the sliding window is, and the greater the decoding error is. Therefore, under the circumstances that mobile node moves slowly, we need to increase the sliding window length appropriately; otherwise, we need to decrease. Therefore, the sliding window length can be selected according to the moving model of the mobile node.

The principle of Variable length sliding window is as follows: the sender maintains a continuous data set to be sent, called the sending window; at the same time, the receiver also maintains a continuous data set to be received, called the receiving window. Variable length sliding window need two windows: the sender maintains a continuous sending data packet sets, called the sending window; at the same time, the receiver will maintain a set of continuous data packet sets, called the receiving window.

The window is used for store data packet during encoding packet and packet transmission. When updating data, the window will slide. According to the principle of sliding window, the window data should be sent to the sender and the receiver to receive the data within the window. The sending window is used to implement data packet stream control. The receive window is used to control data packet received.

3.1 The Sliding Window Model

The network is represented as $G=(V, E)$ where V represents the set of nodes in the network and E denotes the set of directed edges. Each link $e=(i, j)\in E$ means that node i can transmit to node j. We assume links are symmetric that if $(i, j)\in E$; $(j, i)\in E$ as well. Whether two links interfere with each other depends on the interference model adopted.

Suppose that, $P=(P_1, P_2, \dots, P_m)$ is a finite set. A transaction $T=(t_{id}, x_1, x_2, \dots, x_n)$, $x_i\in P$, is a finite set where n and t_{id} are the number of sets in the transaction and transaction identifier, respectively. A finite set X is a non-empty subset of finite field. We called an item set a K-finite field set if it has exactly K finite field. Transactional data packet stream $T=(T_1, T_2, \dots, T_n)$ is a sequence of transactions in which T_n is the most recent transaction. Sliding window $\mathrm{SW}_{n-|w|+1}=(T_{n-|w|+1}, T_{n-|w|+2}, \dots, T_n)$ defined on T contains $|W|$ recent transactions of T, where $|W|$ and n-$|W|$+1 are window size and window identifier, respectively. SW slides forward when a new transaction arrives from T by inserting the new transaction to SW and deleting the oldest one from the window. The sliding window model of the packet stream is shown in Fig. 1.

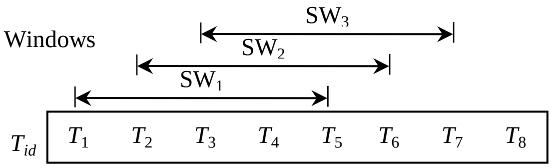

Figure 1: Processing a data stream using sliding window model.

In Fig. 1, the window size is 5. First sliding window SW_1 is formed by first 5 transactions. The other sliding windows are SW_2 and SW_3, each of which is formed by inserting a new transaction to its previous sliding window and deleting the oldest transaction from the window. The current sliding window is the last sliding window SW_3. Given a minimum support threshold, the problem is defined as finding the set of closed frequent item sets within the current sliding window. The mining result must be updated by every window sliding.

3.2 Smooth Functions

Sliding Windows: Let D and R be two finite sets and f: $D^n \rightarrow R$ be a function over strings of length n. We define the operation SLIDING-WINDOW, denoted Γ, that takes f and returns a function $f^{\Gamma t}$: $D^{n+t-1} \rightarrow R^t$, defined by $f^{\Gamma t}(x) = (f(x_i, \dots, x_{i+n-1}))^t_{i=1}$. We concentrate on the case that $t = n$ and apply the SLIDING-WINDOW operator to the functions F_k, F_k mod 2, ED, and O_t, the t-th order statistic. We will use the notation $F^{(j)}{}_k$ (resp. $f^{(j)}{}_i$) to denote the k^{th} frequency moment (resp. the frequency of symbol i) of the string in the window of length n starting at position j.

Definition 1: ((ε, ε')-smooth function [23]) Let f be a function defined on sets of points, and let $\varepsilon, \varepsilon' \in (0, 1)$. We say f is an (ε, ε')-smooth function if f is non-negative (i.e., $f(A)\geq 0$ for all sets A), non-decreasing (i.e., for $A \subseteq B$, $f(A)\leq f(B)$), and polynomial bounded (i.e., there exists constant $c>0$ such that $f(A)=O(|A|^c)$) and for all sets A, B, C.

$$f(B)\geq(1-\varepsilon)f(A\cup B) \text{ implies } f(B\cup C)\geq(1-\varepsilon')f(A\cup B\cup C) \quad (1)$$

3.3 Variable Length Sliding Window

The conventional sliding window algorithm using a fixed window length, the computational complexity of the algorithm can increase the additional and proportional to the length of the sliding window. In order to effectively improve the performance of sliding window, we proposed a variable sliding window algorithm using a network coding length. Variable length sliding window algorithm of the general structure and process the same as the traditional sliding window algorithm, just in the process according to the performance of variable window to resize the sliding window. The variable length sliding window of algorithm will be variable set the length of each sliding window, which can avoid the length of the sliding window is too big or too small.

Fig. 2 illustrates the conceptual structure of the proposed variable length sliding window algorithm with a sliding window length of w information bits and a frame length of N information bits, assumed to be an integer multiple of w. Let us define the i-th forward recursion and the i-th backward recursion computation ($1\leq i\leq N/w$) as the forward metric and backward recursion computation computed from the beginning of the (i-1)-th sliding window to the beginning of the i-th sliding window, respectively.

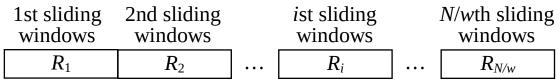

Figure 2: Depiction of the proposed variable sliding window algorithm.

In the conventional sliding window algorithm, the length of the sliding window is fixed for all encoding windows, decoding windows and all decoder iterations. However, in the proposed variable length sliding window algorithm, the length of the sliding window is variable varied for each encoding windows, decoding window and each iteration depending on the reliability information obtained from the backward recursion.

We define the following formula to aggregate the most recent received packet R_i, given the packet R_i is the i-th packet in current sliding window W_i.

$$Ri = \rho \bullet f(i) + (1\text{-}\rho) \bullet Ri\text{-}1, \text{ and } f(i) = k \bullet i + C \qquad (2)$$

where ρ is the weight assigned to the predictive sliding window value of latest received packet in window W_i. $f(i)$ is the linear regression function on packets. When the behavior of a service changes, current sliding window value R_i will be updated in a new sliding window, therefore current sliding window may be updated as the new sliding window.

4 NETWORK CODING MECHANISM

4.1 Linear Algebra over Finite Fields

Let $\boldsymbol{F}=GF(2)$ be the finite field of order 2. Let $\boldsymbol{U} = GF(2^n)$ and $\boldsymbol{V} = GF(2^m)$ denote two extension fields of $\boldsymbol{F}$, where n and m are positive integers. $\boldsymbol{U}$ and $\boldsymbol{V}$ can also be regarded as two vector spaces over $\boldsymbol{F}$ with dimension n and m, respectively, and we write $\boldsymbol{U} = \boldsymbol{F}^n$ and $\boldsymbol{V} = \boldsymbol{F}^m$.

Definition 2: Let $f : \boldsymbol{U} \rightarrow \boldsymbol{V}$ be a mapping. If f satisfies the following properties:

(1) $f(\alpha+\beta) = f(\alpha) + f(\beta)$, for all $\alpha, \beta \in \boldsymbol{U}$,

(2) $f(c\alpha) = cf(\alpha)$, for all $c \in \boldsymbol{F}$, $\alpha \in \boldsymbol{U}$.

We say that it is a linear mapping from vector space $\boldsymbol{U}$ to $\boldsymbol{V}$.

Let $\boldsymbol{F}^{n\times m}$ denote the set of all $n\times m$ matrices over $\boldsymbol{F}$. Suppose $\{\alpha_1, \alpha_2, \dots, \alpha_n\}$ is a basis of $\boldsymbol{U}$ and $\{\beta_1, \beta_2, \dots, \beta_m\}$ is a basis of $\boldsymbol{V}$. For each $f \in \boldsymbol{L}(\boldsymbol{U}, \boldsymbol{V})$, there exists a unique matrix $\boldsymbol{A} \in \boldsymbol{F}^{m\times n}$ such that

$$((\alpha_1), f(\alpha_2), \dots, f(\alpha_n)) = (\beta_1, \beta_2, \dots, \beta_m)\boldsymbol{A}$$

Then, $(y_1, y_2, \dots, y_m)^{\mathrm{T}} = \mathbf{A}(x_1, x_2, \dots, x_m)^{\mathrm{T}}$

where $\alpha = x_1\alpha_1 + x_2\alpha_2 + \dots + x_n\alpha_n$ and $\beta = y_1\beta_1 + y_2\beta_2 + \dots + y_n\beta_n$. $\boldsymbol{A} \in \boldsymbol{F}^{m\times n}$ is called the transition matrix from α to β. According to the previous correspondence, we use f_A to denote the mapping in $L(U, \boldsymbol{V})$ whose corresponding matrix is $\boldsymbol{A} \in \boldsymbol{F}^{m\times n}$ with respect to the bases $\{\alpha_1, \alpha_2, \dots, \alpha_n\}$ and $\{\beta_1, \beta_2, \dots, \beta_m\}$.

4.2 Network Coding

Before transmitting a message M, a source node $\boldsymbol{S}$ first partitions the message into a sequence of m vectors, $P_1, P_2, \dots, P_m \in \boldsymbol{F}^m$. Next, the source $\boldsymbol{S}$ generates m augmented vectors by appending m symbols on the original ones, and the resulted vectors $M_1, M_2, \dots, M_m$ are given by

$$M_i = (P_i, \overbrace{\underbrace{0, \dots, 1}_{i}, 0, \dots, 0}^{m}) \in \boldsymbol{F}^{n+m},\ i \in \{1, 2, \dots, m\} \qquad (3)$$

Assume that a number of original packets $M_1, \dots, M_n$ are generated at the source node. In PNC, a sequence of coefficients $c_1, \dots, c_n$ is picked up from $GF(2^s)$. The encoded packet is

$$X = \sum_{i=1}^{n} c_i X_i \qquad (4)$$

where the last m symbols of X denote the global coding coefficients c_i.

4.3 Transfer Process

We can take several original packets and generate linear combinations of them over a finite field using random coefficients. The basic operations performed in a network coding system are depicted in Fig. 3. The encoder generates linear combinations of the original data packets in the current generation.

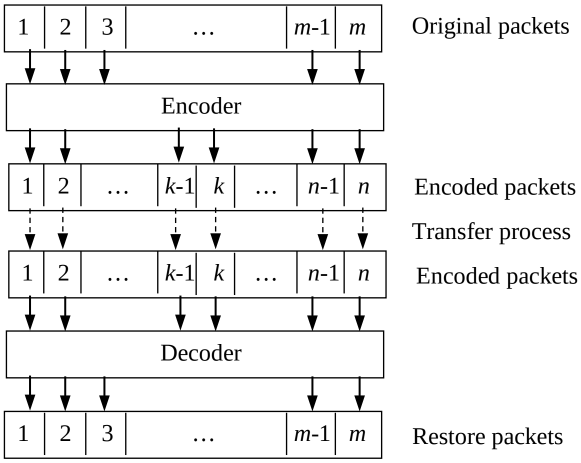

Figure 3: Transfer process of network coding.

The middle layer represents the wireless channel, where packets are lost depending on the channel conditions. The received encoded packets are passed to the decoder, which will be able to reconstruct the original data packets after receiving at least g linearly independent packets. The receiving node is decoding data packets, to restore the original data packets. Moreover, a receiver is no longer required to gather all data packets one-by-one, it can simply "hold a bucket" for a generation until it is full, that is more than m linearly independent encoded packets are received.

4.4 Analysis

We assume that the node has sliding window of size W for the packets sent. Let t_i denote the sliding window time for packet i, and $D_i(t_i)$ denote the contribution of packet i sliding window for t_i seconds to decoding a coded packet. In other words, $D_i(t_i)$ represents the amount of decoded data packets by packet i if it is sliding window for t_i seconds. Our design objective is to maximize the total contribution DW:

$$\text{Maximize } \ D_W = \sum_i D_i(t_i), \ \ s.t. \ \sum_i (s \times t_i) \le s \times W \times T \qquad (5)$$

where s is the packet size, W is the sliding window size measured in packets, and T is the working time of the sliding window.

We classify the packets with the same sliding window time into a group and denote by n_k the number of packets in group k. So, the design objective is equivalent to

$$\text{Maximize } \ D_W = \sum_k n_k D_k(t_k) \qquad (6)$$

Here, we define decoding efficiency of the sliding window as

$$E_W = \frac{D_W}{s \times W \times T} \qquad (7)$$

and define decoding efficiency of packet *i* as

$$E_i(t_i) = \frac{D_i(t_i)}{s \times t_i} \tag{8}$$

According to (5)–(8), the design objective can be rewritten as
Maximize

$$E_W = \sum_k \left(\frac{n_k t_k}{W \times T} \bullet \frac{D_k(t_k)}{s \times t_k}\right) = \sum_k a_k E_k(t_k) \tag{9}$$

where a_k is the sliding window of group *k*:

$$a_k = \frac{n_k t_k}{W \times T} \tag{10}$$

Suppose that we define the cumulative distribution function (cdf) of coded packet latency $C(t)$ as the probability that the coded packet latency is smaller than or equal to *t* seconds and its corresponding probability density function (pdf) is denoted by $p(t)$.
The contribution to decoding a coded packet if a sliding window packet can be used for decoding in *t* seconds since its arrival, is given by

$$R(t)=s \bullet C(t) \tag{11}$$

The corresponding decoding efficiency is given by

$$E(t) = \frac{R(t)}{s \bullet t} = \frac{C(t)}{t} \tag{12}$$

The maximal sliding window decoding efficiency can be approximately sliding window through maximizing individual packet decoding efficiency.
At any time *t*, we analyze the detection complexity of the VLSW-NC algorithm. It can be seen that the decoding complexity of VLSW-NC is much smaller than that of TCP/NC. It is found that to decode TCP/NC, the forward elimination is the dominating part (i.e., $O(W^3)$) as *W* increases and hence the average complexity for decoding an original packet is $O(W^2)$. For VLSW-NC, the decoding coefficient matrix of the receiver is sparse since it has smaller number of non-zero items. Thus the improved VLSW-NC scheme decreases the detection complexity of destination evidently.

5 SIMULATION EXPERIMENTS

5.1 Simulation Scenario

In this section, we present computer simulation results in order to demonstrate the efficiency of the proposed a Variable Length Sliding Window-based Network Coding Algorithm in MANETs (VLSW-NC). The proposed algorithm was compared with delay controlled network coding (DCNC) [15] and Transmission Control Protocol with network coding (TCP/NC) algorithm [17] in MANET environment. We use the NS-2 simulator [24] to evaluate the throughput, packet loss probability, decoding delay for VLSW-NC in MANETs.
In our simulations, the available wireless bandwidth is 5Mb/s, the packet queue size is 1000 packets, and the receive window is 200 packets. Each packet is 256 B and each ACK is 40 B. The corresponding simulation parameters are summarized in Table 1.

Table 1: Simulation Parameters

Number of nodes	100
Network area	1000m × 1000 m
Transmission range	250 m
Simulation time	600 s
Transmission range	250 m
Beacon period	100 ms
Communication model	Constant Bit Rate (CBR)
Message size (b_{msg})	512 bytes/packet
Examined routing protocol	DCNC [15], TCP/NC [17]

5.2 Sample Fabrication

Fig. 4 show the simulated throughput curves under the wireless channel for the VLSW-NC, the TCP/NC, and the DCNC algorithms with Variable length sliding window of packet sizes. From the Fig. 4, we can see that the achieved throughput of VLSW-NC is highest. Therefore, we can see that by taking advantage of Variable length sliding window network coding, VLSW-NC is effective in improving the network throughput.

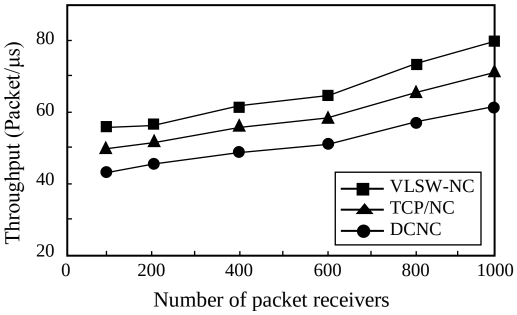

Figure 4: Network throughput vs. Number of packet receivers.

In Fig. 5, we study the effect of variable length sliding window on the packet loss ratios of VLSW-NC and TCP/NC and DCNC under different number of packet receivers. The packet loss counted in the simulation can occur at any clients in the MANET. From the Fig. 5, it can be seen that the packet loss probability drops almost exponentially with the increase of number of packet receivers. Moreover, we can see the requirement of packet loss probability of 10^{-10} can be satisfied with variable length sliding window.

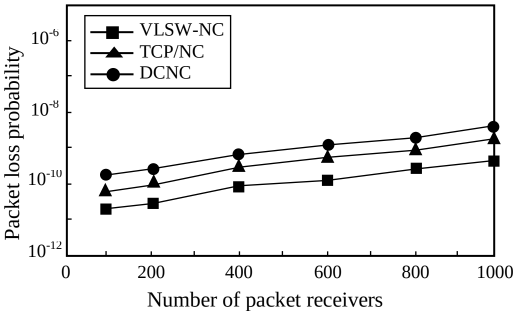

Figure 5: Packet loss probability vs. Number of packet receivers.

In Fig. 6, we compare the achievable decoding delay of VLSW-NC with those of TCP/NC and DCNC under number of packet receivers. We can also see from Fig. 6 that the VLSW-NC algorithm has the lowest decoding delay. This is because VLSW-NC algorithm uses the variable length sliding window mechanism, which has the optimal number of decoding groups in the Variable length sliding window.

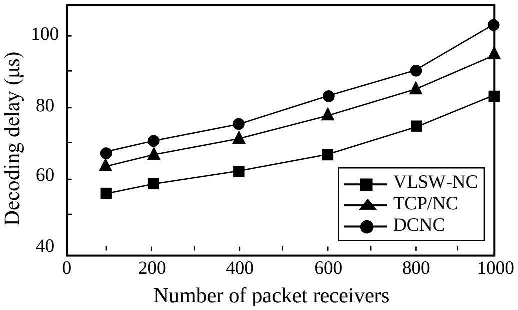

Figure 6: Decoding delay vs. Number of packet receivers.

4 CONCLUSIONS

In this paper, we combine the sliding window with the network coding to obtain the desired reliability in MANET. We present a Variable Length Sliding Window-based Network Coding algorithm in MANETs (VLSW-NC). Then, theoretical analysis is presented to verify the better performance of proposed VLSW-NC scheme. It is typically proposed in order to decrease the decoding delay and packet loss probability of data transmission, by applying network coding and sliding window which allows packet encoding at a variable length sliding window. The analysis shows that VLSW-NC produces higher reliability and throughput. This technique can guarantee the same reliability while consume the least encoding and decoding. This feature is important in MANETs since it can increase network performance and reliability.

ACKNOWLEDGMENTS

This work was partially supported by the National Natural Science Foundation of China under grant 61572012. The Natural Science Foundation of Hubei Province of China under grant 2017CFB773.

REFERENCES

[1] B. L. Sun, C. Gui, Y. Song, and H. Chen. 2014. A Novel Network Coding and Multi-path Routing Approach for Wireless Sensor Network. Wireless Personal Communications, 77(1): 87–99.
[2] A. H. Mohammed, B. Dai, B. X. Huang, M. Azhar, G. Xu, P. Q. , S. Yu. 2013. A survey and tutorial of wireless relay network protocols based on network coding. Journal of Network and Computer Applications, 36(2): 593–610.
[3] B. L. Sun, Y. Song, C. Gui, M. Luo. 2014. Network Coding-Based Priority-Packet Scheduler Multi-path Routing in MANET using Fuzzy Controllers. International Journal of Future Generation Communication and Networking, 7(2): 137–147.
[4] R. Ahlswede, N. Cai, S.-Y.R. Li, R. W. Yeung. 2000. Network information flow. IEEE Transactions on Information Theory, 46(4): 1204–1216.
[5] R. W. Yeung. 2011. Network coding: A historical perspective. Proceedings of the IEEE, 99(3): 366–371.
[6] S. Jaggi, P. Sanders, P. A. Chou, et al. 2005. Polynomial Time Algorithms for Multicast Network Code Construction. IEEE Transactions on Information Theory, 51(6): 1973–1982.
[7] T. Aktas, Y. A. Ozgür, E. Aktas. 2013. Practical methods for wireless network coding with multiple unicast transmissions. IEEE Transactions on Communications, 61(3): 1123–1133.
[8] Y. Lin, B. Liang, B. Li, 2010. SlideOR: online opportunistic network coding in wireless mesh networks, IEEE INFOCOM (2010) 171–175.
[9] M. Kwon, H. Park, N. Thomos, P. Frossard. 2016. Approximate decoding for network coded inter-dependent data. Signal Processing, 120: 222–235.
[10] R. Louie, Y. Li, B. Vucetic, 2010. Practical physical layer network coding for two-way relay channels: performance analysis and comparison, IEEE Transactions on Wireless Communications, 9 (2): 764–777.
[11] N. M. Jones, B. Shrader, E. Modiano, 2012. Optimal routing and scheduling for a simple network coding scheme, IEEE INFOCOM (2012): 352–360.
[12] S. Sengupta, S. Rayanchu, S. Banerjee, 2010. Network coding-aware routing in wireless networks, IEEE/ACM Transactions on Networking, 1028–1036.
[13] J. Le, C.-S. Lui, D.-M. Chiu, 2010. DCAR: Distributed coding-aware routing in wireless networks, IEEE Transactions on Mobile Computing, 9(4): 596–608.
[14] H. Chen, Y. Liu, T. Qin, H. Yao, Q. Tang. 2014. Construction of Structured q-ary LDPC Codes over Small Fields Using Sliding-Window Method. Journal of Communications and Networks, 16(5): 479-484.
[15] Y. Qu, C. Dong, C. Chen, H. Wang, C. Tian, S. Tang. 2016. DCNC: throughput maximization via delay controlled network coding for wireless mesh networks. Wireless Communications and Mobile Computing, 16(1): 137-149.
[16] X. Li, C.-C. Wang, X. Lin, 2011. On the capacity of immediately-decodable coding schemes for wireless stored-video broadcast with hard deadline constraints, IEEE Journal on Selected Areas in Communications, 29(5): 1094-1105.
[17] P. Karafillis, K. Fouli, A. ParandehGheibi, and M. Médard. 2013. An Algorithm for Improving Sliding Window Network Coding in TCP. 47th Annual Conference on Information Sciences and Systems (CISS 2013), Baltimore, MD, USA, March 20-22, 2013: 1-5.
[18] S. Chen, M. Wu, K. Wang, Z. Sun, W. Lu. 2015. Combining network coding and compressed sensing for error correction in wireless sensor networks. International Journal of Communication Systems, 28(7): 1303–1315.
[19] D. Zeng, S. Guo, J. Hu, 2014. Reliable bulk-data dissemination in delay tolerant networks. IEEE Transactions on Parallel and Distributed Systems, 25 (8): 2180–2189.
[20] H. Khamfroush, D. Lucani, P. Pahlevani, J. Barros. 2015. On optimal policies for network-coded cooperation: Theory and implementation. IEEE Journal on Selected Areas in Communications, 33 (2): 199–212.
[21] F. Wua, C. Hua, H. Shan, A. Huang. 2015. Cooperative multicast with moving window network coding in wireless networks. Ad Hoc Networks, 25: 213–227.
[22] H. Lim, Y. Kim, K. Cheun. 2012. An Efficient Sliding Window Algorithm Using Adaptive-Length Guard Window for Turbo Decoders. Journal of Communications and Networks, 14(2): 195-198.
[23] V. Braverman and R. Ostrovsky. 2010. Effective computations on sliding windows. SIAM Journal on Computing, 39(6): 2113–2131.
[24] The Network Simulator - NS-2, http://www.isi.edu/nsnam/ns/.