様　式　Ｃ－１９、Ｆ－１９－１、Ｚ－１９　（共通）

科学研究費助成事業　　研究成果報告書

令和　３ 年　 ６ 月 １６ 日現在

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研究課題名（和文）Reliable data transfer on diverse and dynamic IoT environments by TCP with Network Coding

研究課題名（英文）Reliable data transfer on diverse and dynamic IoT environments by TCP with Network Coding

研究代表者

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交付決定額（研究期間全体）：（直接経費）　　1,800,000円

研究成果の概要（和文）：私の研究は、パケットロスの多いネットワークのためのTCP/NCプロトコルを改善し、さらにTCP/NCプロトコルを利用したTCP/NCトンネリングを提案することに焦点を当てています。改善されたTCP/NCは、PLCネットワーク、バースト性のあるパケットロスが頻繁に起きるネットワーク、双方向のパケットロスがあるネットワーク、マルチパスネットワークなどの多くのシナリオに適用できます。 さらに、提案されたTCP/NCトンネリングは、TCP/NCを適用できないようなシナリオ、例えばエンドデバイスの資源制限が強いIoTネットワークなどにおいても、パケットロスの多い状況でのグッドプットを向上を可能にします。

研究成果の学術的意義や社会的意義
With the proposed model of TCP/NC tunneling, we can apply the advantage of TCP/NC on the practical IoT networks where the link is almost unstable, lossy. It can improve the data transfer performance to adapt to the requirement of IoT scenarios, e.g., the next generation of cloud/edge computing.

研究成果の概要（英文）：My research focuses on improving TCP/NC protocol and proposing its application called TCP/NC tunneling in the lossy network. The proposed TCP/NC can apply in many scenarios such as PLC networks, heavy and burst lossy networks, bi-directional loss networks, and multipath networks. And the proposed TCP/NC can achieve a high goodput performance compared to other protocols. Besides, the proposed TCP/NC tunneling also proves its advantage in applying some specific scenarios, such as IoT networks, where cannot apply TCP/NC (e.g., limitation of end devices)

研究分野：Network Protocol

キーワード：TCP/NC　Tunneling　Error recovery　Congestion control　Redundancy control　Path optimization　IoT　Network Coding

様　式　Ｃ－１９、Ｆ－１９－１、Ｚ－１９（共通）

１．研究開始当初の背景

Transmission Control Protocol (TCP), as transport layer communications protocol between end-nodes, has a long history with gradual improvements and is still dominant for reliable end-to-end data transfer with network congestion control. However, TCP cannot operate effectively (e.g., low data goodputs) on lossy networks especially with a long Round-Trip Time (RTT).

One the other hand, the demand for Internet of Things (IoT) applications is growing rapidly with penetration of IoT devices in wild and diverse network environments, e.g., Power Line Communications (PLC), Low-Power Wide-Area (LPWA) wireless networks, and Vehicular Ad-hoc Networks (VANET), which are often characterized by a high loss rate and/or a long RTT. In addition, the performance of end-to-end data transfer should be considered from diverse aspects such as goodput, latency, and energy-efficiency. One extreme approach is an individually optimized transport layer for each environment that should be implemented on all end-devices but seems unpractical due to its deployment costs. Therefore, how to realize end-to-end data transfer effectively in such IoT environments with no or few changes of end-device's communication protocol stack is a key challenge to support the future smart society.

２．研究の目的

Purpose of the research is improving the TCP/NC in many IoT scenarios, such as (1) heavy and burst lossy networks (e.g., wireless multi-hop networks) where the packet loss rate is high and many packet losses occur consecutively, (2) multipath networks where the packet can arrive the destination not in order, (3) bi-directional loss networks where the packet loss in both directions, and (4) PLC networks.

Besides, we propose the new TCP/NC tunneling model to bring the TCP/NC’s advantage in some specific networks where cannot apply the TCP/NC on some devices (e.g., due to the limitation of the hardware). TCP/NC tunneling can help to improve the performance of the current IoT network with no or few changes of end-device's communication protocol stack.

３．研究の方法

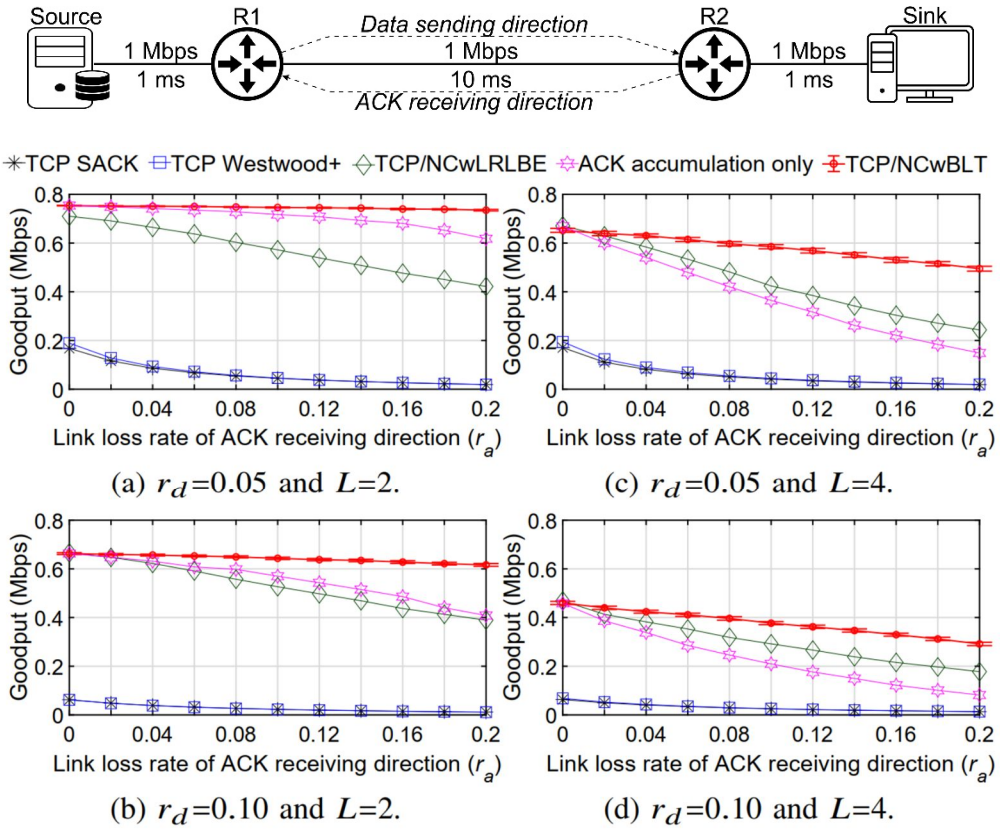
a. We study and investigate the lossy networks to know the packet loss behavior.
b. We emulate the packet loss in the simulation tool of ns-3 (Network Simulator 3).
c. Based on each packet loss behavior. We propose the new algorithm to overcome the packet loss and improve the transmission performance of TCP/NC.
d. We implement the new algorithm and test it on ns-3.
e. We compare the new proposal and the previous, traditional protocol to evaluate the proposal.

４．研究成果

We proposed 3 enhanced version of TCP/NC in 3 specific scenarios and one enhanced TCP tunneling:

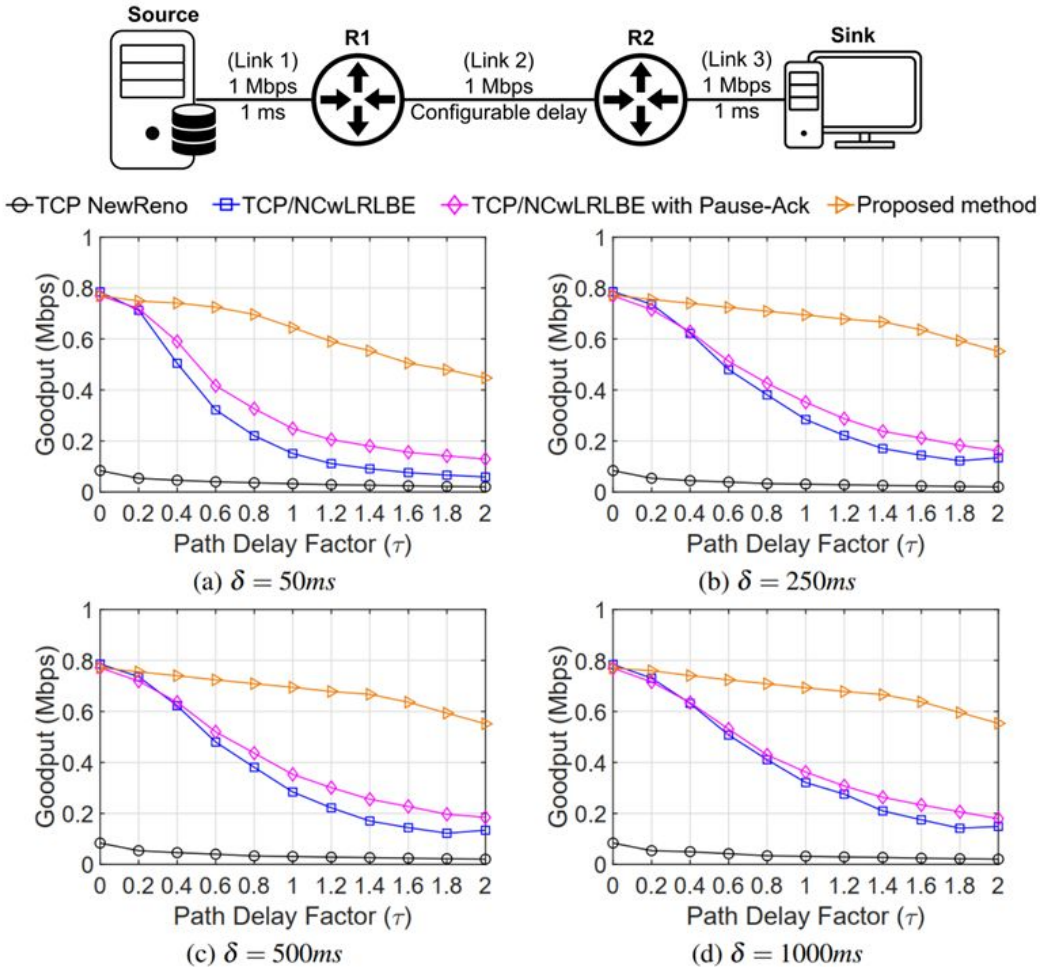
a. TCP/NC with Bidirectional Loss Tolerance (TCP/NCwBLT).

The proposed TCP/NCwBLT can work in bi-directional and burst loss conditions for reliable and efficient data transmission in severe environments. Our technical contributions include adding 32-bit information on recent data arrivals into the NC-ACK header, introducing a timer-based ACK retransmission at the sink, and a duplicate ACK generator at the source. Those enhancements make precise data loss estimation and TCP retransmission significantly robust and fast in bi-directional loss condition, especially with burst ACK loss, and thus increase both the bandwidth efficiency and longterm goodput. The proposed TCP/NCwBLT outperforms TCP SACK, TCP Westwood+, and the recent variant of TCP/NC (e.g., TCP/NCwLRLBE) in synthetic simulation scenarios.



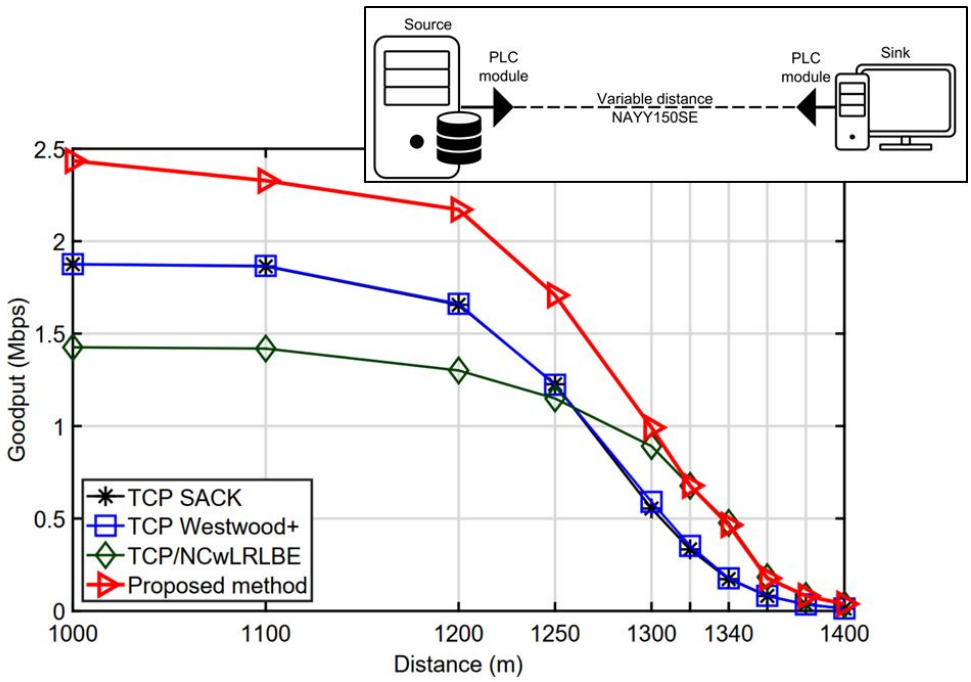
b. TCP/NC with Packet Reordering Tolerance (TCP/NCwPRT).

The proposed the scheme can estimate and adapt to the packet reordering; therefore, TCP/NCwPRT can work well on receiving out-of-order packet scenarios, which may sometimes happen in most practical complex network environments, e.g., multipath networks, mobility. The simulation results on ns-3 have shown that TCP/NCwPRT can maintain the TCP goodput well in a wide range of packet reordering environments compared to TCP NewReno as well as TCP/NC.



c. TCP/NC with ACK Skipping (TCP/NCwAS).

TCP/NCwSA is to improve the TCP/NC in half-duplex communication networks. It can determine the number of ACK packets that can be skipped based on the channel conditions. According to the determined skip interval, unnecessary ACK packets will not

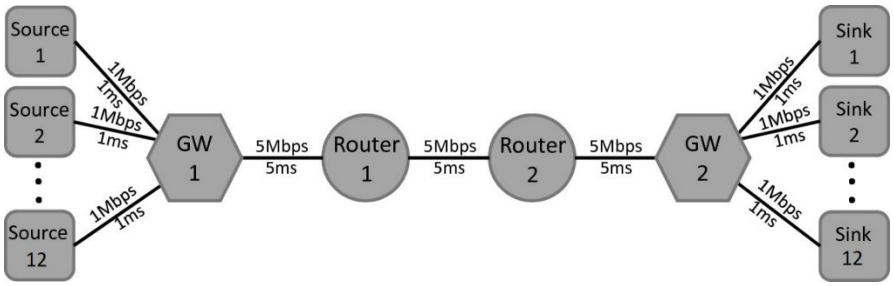


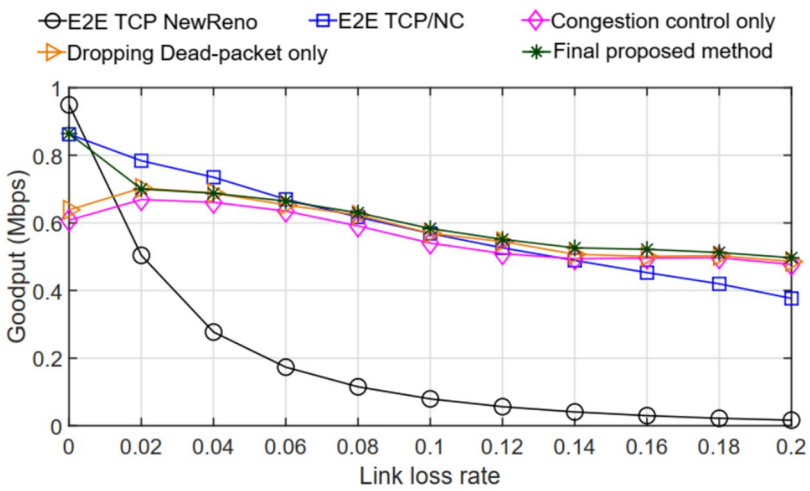
be sent unless a timeout happens. We evaluate the proposal, TCP with Selective

Acknowledgment (TCP SACK), TCP Westwood+, and the recent variant of TCP/NC (e.g.,TCP/NCwLRLBE) in simple PLC network simulation on ns-3. The simulation result shows that the proposal achieves a higher goodput on PLC environment compared to TCP with Selective Acknowledgment and TCP Westwood+ as well as the recent variant of TCP/NC.

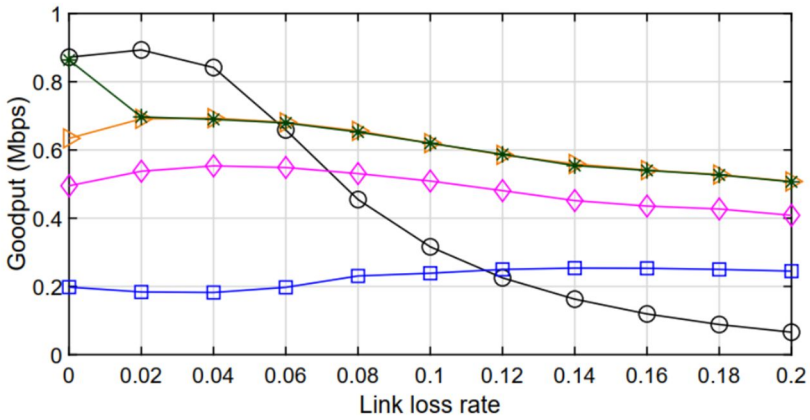
d. Enhanced TCP/NC Tunneling

We proposed a new enhanced TCP/NC tunnel system in term of buffer management for lossy and congestion networks. It can intentionally drop overloaded packets or useless dead packets before they enter the TCP/NC tunnel. The simulation results show that the proposal can achieve a good goodput compare to others.





(a) Three sessions



(b) Twelve sessions

５．主な発表論文等

〔雑誌論文〕　計6件（うち査読付論文　6件／うち国際共著　2件／うちオープンアクセス　0件）

１．著者名 N. V. Ha, T. T. T. Nguyen, and M. Tsuru	４．巻 24(2)
２．論文標題 TCP with Network Coding Enhanced in Bi-directional Loss Tolerance	５．発行年 2019年
３．雑誌名 IEEE Communications Letters	６．最初と最後の頁 520-524
掲載論文のDOI（デジタルオブジェクト識別子） 10.1109/LCOMM.2019.2961096	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 －

１．著者名 N. V. Ha, M. Tsuru	４．巻 X8-B(12)
２．論文標題 Buffer Management for TCP/NC Tunnel in Lossy and Congested networks	５．発行年 2019年
３．雑誌名 IEICE Communications Express	６．最初と最後の頁 530-535
掲載論文のDOI（デジタルオブジェクト識別子） 10.1587/comex.2019GCL0035	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 －

１．著者名 N. V. Ha, L. V. Hau, T. T. T. Nguyen, M. Tsuru	４．巻 ICACT 2020
２．論文標題 Dynamic ACK skipping in TCP with Network Coding for Power Line Communication Networks	５．発行年 2020年
３．雑誌名 IEEE International Conference on Advanced Communications Technology (ICACT)	６．最初と最後の頁 29-34
掲載論文のDOI（デジタルオブジェクト識別子） 10.23919/ICACT48636.2020.9061477	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 該当する

１．著者名 N. V. Ha, L. V. Hau, T. T. T. Nguyen, and M. Tsuru	４．巻 ICSSE 2019
２．論文標題 The performance characteristics of TCP with Network Coding in Power Line Communication Network	５．発行年 2019年
３．雑誌名 International Conference on System Science and Engineering	６．最初と最後の頁 267-272
掲載論文のDOI（デジタルオブジェクト識別子） 10.1109/ICSSE.2019.8823099	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 該当する

1．著者名 Nguyen Viet Ha, Masato Tsuru	4．巻 ICEIC 2019
2．論文標題 TCP/NC performance in bi-directional loss environments	5．発行年 2019年
3．雑誌名 International Conference on Electronics, Information, and Communication	6．最初と最後の頁 4 pages
掲載論文のDOI（デジタルオブジェクト識別子） 10.23919/ELINFOCOM.2019.8706367	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 －

1．著者名 Nguyen Viet Ha, Masato Tsuru	4．巻 EIDWT 2019
2．論文標題 TCP with network coding performance under packet reordering	5．発行年 2019年
3．雑誌名 International Conference on Emerging Internet, Data and Web Technologies (EIDWT)	6．最初と最後の頁 552-563
掲載論文のDOI（デジタルオブジェクト識別子） 10.1007/978-3-030-12839-5_51	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 －

〔学会発表〕　計2件（うち招待講演　0件／うち国際学会　0件）

1．発表者名 Nguyen Viet Ha
2．発表標題 Tolerance of TCP with Network Coding to Reverse-direction Packet Loss and Packet Reordering
3．学会等名 IEICE Technical Committee on Information Networks
4．発表年 2018年

1．発表者名 Nguyen Viet Ha
2．発表標題 On Buffer Management for TCP/NC Tunneling
3．学会等名 IEICE General Conference
4．発表年 2019年

〔図書〕　計0件

〔産業財産権〕

〔その他〕

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６．研究組織

	氏名 （ローマ字氏名） （研究者番号）	所属研究機関・部局・職 （機関番号）	備考

７．科研費を使用して開催した国際研究集会

〔国際研究集会〕　計0件

８．本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関