

ENHANCED TCP'S CONGESTION CONTROL MECHANISMS OVER
LONG TERM EVOLUTION NETWORKS

MOHANAD NASER ABDULLAH AL-HASANAT



بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

وَلَوْ أَنَّمَا فِي الْأَرْضِ مِنْ شَجَرَةٍ أَقْلَمٌ وَالْبَحْرُ يَمُدُّهُ مِنْ بَعْدِهِ،
سَبْعَةَ أَبْحُرٍ مَّا نَفِدَتْ كَلِمَاتُ اللَّهِ إِنَّ اللَّهَ عَزِيزٌ حَكِيمٌ ﴿٢٧﴾

صَدَقَ اللَّهُ الْعَظِيمُ

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Dedicated to my father Naser Al-Hasanat, my mother, my brothers, my sisters, my children, and to you my beloved wife ♥

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ABSTRACT

Wireless technologies have experienced intensive improvements in the past two decades. New technologies, expensive applications, and new specifications have been rapidly introduced. The latest were the Long Term Evolution (LTE), LTE-Advanced, and WiMAX-Advanced marketed as 4G. One other is the Transmission Control Protocol (TCP), which is the most widely used transport protocol in today's networks. The TCP was designed as a reliable transport protocol over wired links, where losses rarely occur but generally indicate congestion. However, in wireless networks, losses are often caused by the wireless transmission medium, and include fading, interference, and node mobility. Unfortunately, TCP congestion control mechanisms fail to support the new wireless technologies. Significant unfairness and low performance over wireless networks have been reported. Traditional TCP congestion control mechanisms such as Tahoe, Reno, and NewReno incorrectly assume congestion to be the case for every loss event, and unnecessarily reduce transmission rate. Therefore, intensive research has been conducted to combat this harmful failure, and many modifications have been introduced to enhance TCP congestion control mechanisms over wireless networks. Even though these modifications share the same principle of recognizing the cause of the loss, they use different mechanisms to do this incurable task. This means that new modifications and enhancements are still required.

In this study, we introduce a new End-to-End congestion control mechanism to enhance TCP performance over low-latency and wide-bandwidth networks such as LTE networks. The new modification uses a modified TCP Westwood's bandwidth estimation mechanism to preserve the best link utilization, and includes three modifications to the standard TCP congestion control mechanisms. Firstly, we proposed two modifications to the slow start phase. The first is a new mechanism to properly setup the Initial Slow Start Threshold value, and the second proposes a faster start phase to accelerate the Congestion Window growth over the poor utilized links. Secondly, we propose two new modifications to the Fast Retransmission and Fast Recovery mechanism: the faster retransmission and the best recovery. Thirdly, we modified the timeout function to prevent unnecessary congestion avoidance procedures when every timeout occurs. The proposed modifications were integrated into a new TCP congestion control implementation called PETRA using Network Simulator-3 (ns-3). Intensive simulation experiments were conducted to evaluate the new implementation performance over an LTE simulated network. The validation method includes comparing PETRA, NewReno, and TCPW for congestion window behaviour, throughput, average delay, packet loss ratio, jitters, and flow fairness. Simulation results showed significant improvements of the new modification compared to other implementations over long and short latency links, high bit error links, high mobility user equipment, and wide-bandwidth links. Therefore, the new modification is efficient for use as a transport protocol over low-latency and wide-bandwidth networks like LTE networks.

ABSTRAK

Teknologi tanpa wayar (wireless technology) telah mengalami penambahbaikan intensif dalam dua abad yang lepas. Teknologi-teknologi baru, aplikasi-aplikasi baru dan spesifikasi-spesifikasi baru telah diperkenalkan dengan kadar yang cepat. Terbaharu ialah Long Term Evaluation (LTE), LTE-Advanced, WiMAX-Advanced yang dipasarkan sebagai 4G. Satu lagi ialah Transmission Control Protocol (TCP), yang merupakan protokol pengangkutan yang paling banyak digunakan dalam jaringan pada hari ini. TCP direka sebagai protokol pengangkutan yang boleh dipercayai berbanding dengan pautan-pautan berwayar, di mana masalah kehilangan jarang berlaku tetapi kebiasaannya menjadi petanda kepada kesesakan. Namun begitu, dalam jaringan tanpa wayar, masalah kehilangan seringkali berpunca daripada medium transmisi tanpa wayar, yang termasuk keputeraan, gangguan, dan mobiliti nod. Malangnya, mekanisme kawalan kesesakan dalam TCP gagal untuk menyokong teknologi-teknologi tanpa wayar. Ketidakadilan yang signifikan dan prestasi rendah berbanding jaringan tanpa wayar telah dilaporkan. Mekanisme kawalan kesesakan dalam TCP yang berbentuk tradisional seperti Tahoe, Reno, dan NewReno telah bertanggungjawab kepada kesesakan adalah punca bagi setiap kes kehilangan dan kadar transmisi yang berkurangan (yang sememangnya tidak diperlukan). Oleh itu, penyelidikan intensif telah dijalankan untuk menanganikan kegagalan yang memudaratkan ini. Dan banyak perubahan telah diperkenalkan untuk menambahbaik mekanisme kawalan kesesakan dalam TCP berbanding jaringan tanpa wayar. Walaupun modifikasi-modifikasi ini berkongsi prinsip yang sama dalam mengenalpasti sebab kehilangan, mereka menggunakan mekanisme yang berbeza untuk melaksanakan tugas ini. Ini bererti bahawa modifikasi-modifikasi dan perubahan-perubahan masih diperlukan. Dalam kajian ini, kami telah memperkenalkan satu kawalan mekanisme bagi kesesakan (hujung ke hujung) untuk menambahbaik prestasi TCP berbanding dengan kependaman rendah dan lebar jalur lebar rangkaian seperti jaringan LTE. Modifikasi baru ini menggunakan TCP Westwood yang telah diubahsuai dari segi mekanisme anggaran lebar jalur untuk mengekalkan penggunaan link terbaik, dan melibatkan tiga modifikasi kepada mekanisme kawalan kesesakan dalam TCP yang standard. Pertama, kita akan mencadangkan dua modifikasi dalam fasa permulaan yang perlahan. Modifikasi yang pertama ialah mekanisme baru untuk menyediakan nilai Initial Slow Start Threshold secara teratur, dan mekanisme kedua akan melibatkan fasa permulaan yang pantas untuk mempercepatkan pertumbuhan Congestion Window berbanding dengan link-link yang kurang digunakan. Kedua, kami akan mencadangkan dua modifikasi yang baru kepada Fast Retransmission dan mekanisme Fast Recovery. Ketiga, kami akan mengubah fungsi masa tamat untuk mengelakkan daripada prosedur kesesakan yang tidak diinginkan apabila berlakunya masa tamat setiap kali. Modifikasi yang dicadangkan adalah diintegrasikan kepada kawalan kesesakan terbaru TCP yang dikenali sebagai PETRA dengan menggunakan Network Simulator-3 (ns-3). Eksperimen intensif yang berbentuk simulasi telah dijalankan untuk menilai implementasi prestasi berbanding dengan jaringan yang disimulasi oleh LTE. Metod validasi ini melibatkan membandingkan PETRA, NewReno, dan TCPW untuk tingkahlaku tingkap kesesakan, throughput, purata penangguhan, nisbah kerugian paket, kegelisahan dan keadilan dalam aliran. Keputusan simulasi menunjukkan perubahan signifikan dalam modifikasi baru berbanding dengan kaedah-kaedah lain dalam atas pautan latensi panjang dan pendek, pautan ralat bit yang tinggi, peralatan pengguna yang mempunyai mobiliti yang tinggi dan pautan lebar jalur lebar. Maka, modifikasi baru ini adalah efisien untuk penggunaan sebagai protokol

pengangkutan berbanding dengan jaringan yang mempunyai latensi yang rendah dan jaringan yang mempunyai pautan jaluran lebar.

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ملخص البحث

تقنيات الاتصالات اللاسلكية شهدت تطورات كبيرة خلال العقدين الماضيين. تقنيات جديدة، تطبيقات متسعة، بالإضافة الى العديد من الخصائص الجديدة التي تنتج بشكل سريع. آخر هذه التقنيات كان LTE، LTE-Advanced، و WiMAX-Advanced المعروفة في السوق بإسم الجيل الرابع G4. في المقابل هناك بروتوكول النقل الشهير TCP و الذي يعتبر من اشهر بروتوكولات النقل في شبكات اليوم. لقد صمم هذا البروتوكول ليكون موثوق في النقل على الشبكات السلكية، حيث ان اخطاء النقل و ضياع البيانات نادرا ما يحدث و في الغالب يكون اشارة على حدوث ازدحام في نقل البيانات. في المقابل، على الشبكات اللاسلكية يكون ضياع البيانات متكرر الحدوث بسبب وسط النقل الضعيف، اعتراض البيانات، ضعف الاشارة، بالإضافة الى الحركة المستمرة في اطراف الاتصال. لسوء الحظ، فشل TCP في دعم تقنيات الاتصالات اللاسلكية الحديثة. ضعف واضح في توزيع البيانات بالإضافة الى سوء اداء كبير كان من اكثر العيوب التي تم الكشف عنها في العديد من التقارير التي بحثت في اداء TCP على الشبكات اللاسلكية. تقنيات TCP التقليدية فشلت في تحديد سبب ضياع البيانات سواء أكان بسبب الازدحام او بسبب ضعف نواقل الشبكات اللاسلكية. لذلك، اصبح من الصعب استخدام نفس التقنيات القديمة لتمييز سبب ضياع البيانات و الذي يعتبر المؤشر الرئيسي على تشكل الازدحام حسب الفرضية الاساسية التي تم تصميم هذا البروتوكول على اساسها. حيث يقوم هذا البروتوكول بتخفيض حجم البيانات المرسل في حال ضياع حزمه ارسال. لذلك تم اقتراح العديد من التحسينات لتعديل سلوك هذا البروتوكول على الشبكات اللاسلكية. على الرغم من ان معظم المقترحات لتحسين اداء TCP كانت تهدف لتمييز سبب ضياع الحزم، الا انها اختلفت في طريقة فعل ذلك. و بذلك تركت المجال مفتوح لتقديم المزيد من التحسينات و المقترحات.

في هذه الدراسة سوف نقدم مقترح جديد لتحسين اداء تقنية TCP للتحكم في الازدحام على الشبكات اللاسلكية و تحديدا على شبكة LTE. هذا المقترح سوف يستخدم تعديل على التقنية المقترحة في TCP Westwood في التنبأ في القدرة المتاحة لقنوات الاتصال و بالتالي معرفة القدر المستخدم من القناة و تحديد السبب في ضياع الحزم. أولاً، اقترحنا تعديلين لتحسين اداء TCP خلال مرحلة ما يسمى بـ Slow Start من خلال تحديد قيمة أمنة لما يسمى بـ Slow Start Threshold ثم تطبيق التعديل الثاني لتسريع نمو ما يسمى بـ Congestion Window في القنوات التي لا يوجد فيها ازدحام. ثانياً، اقترحنا تعديلين آخرين لتحسين آليات كل من Fast Retransmission and Fast Recovery. ثالثاً، قمنا بتعديل اجراء البروتوكول في حالة فقدان حزمة لحماية من تخفيض سرعة الارسال الا في حين التأكد من وجود ازدحام حقيقي. هذه التعديلات الثلاثة تم دمجها جميعاً في اصدار جديد من الآليات TCP للتحكم في الازدحام تحت اسم PETRA. قمنا باستخدام برنامج المحاكاة ns-3 لتطبيق و التحقق في فعالية الاصدار المقترح. العديد من التجارب اجرية و سيناريوهات مختلفة لمقارنة اداء PETRA مع الاصدارات الاكثر استخداماً في الشبكات اللاسلكية هذه الايام. اظهرت نتائج التجارب جميعها افضلية الاصدار المقترح.

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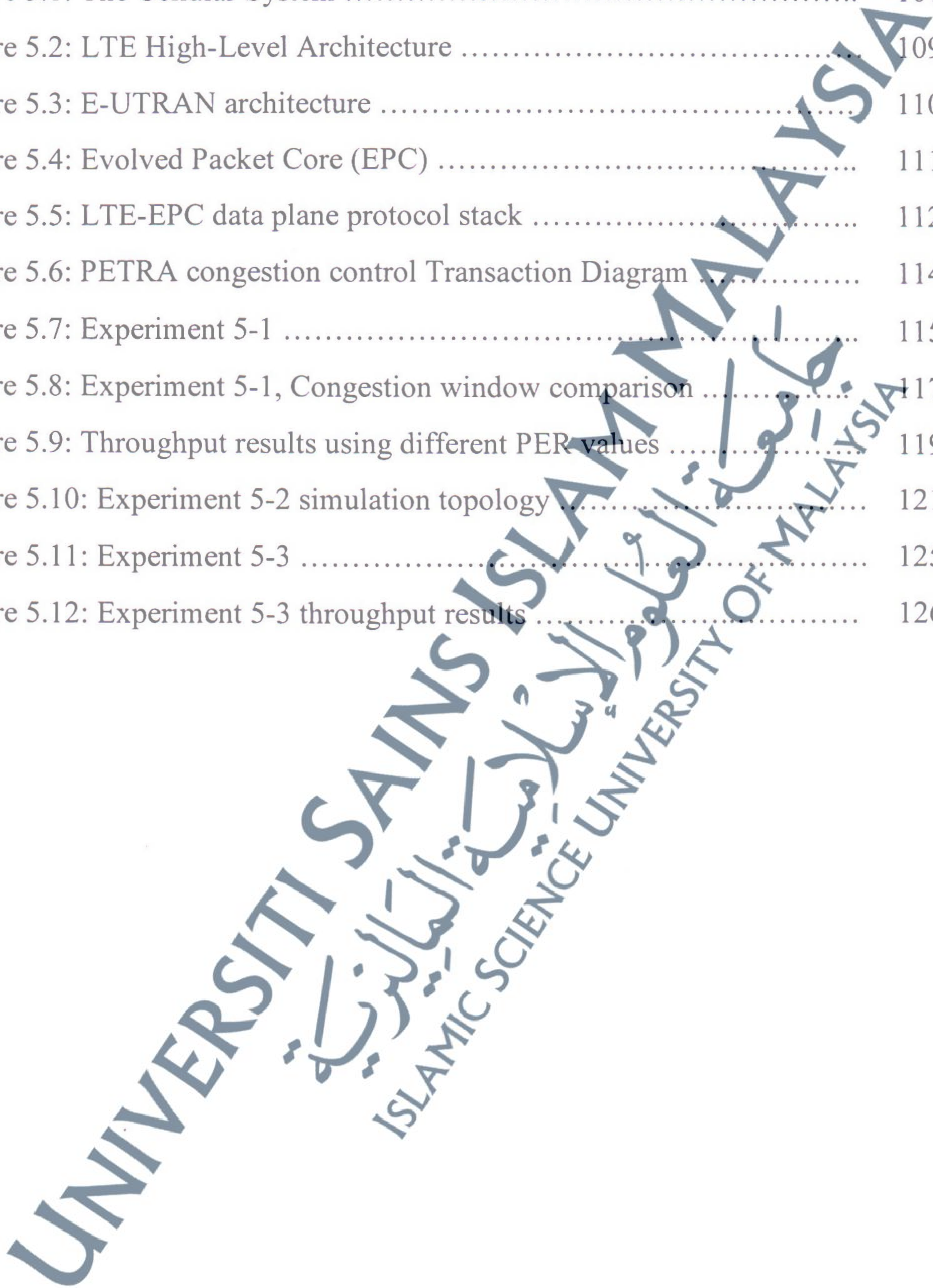
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LIST OF ABBREVIATIONS

3GPP	Third Partnership Project
ACK	Acknowledgment
AFRM	Adaptive FEC-Based Reliable Multicast
AIMD	Additive Increase Multiplicative Decrease
APN	Access Point Name
ARP	Address Reservation Protocol
ARPAnet	Advance Research Project Agency Network
cwnd	Congestion Window
DupACK	Duplicate Acknowledgement
E2E	End-To-End
EPC	Evolved Packet Core
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
FAck	Forward Acknowledgment
FEC	Forward Error Correction
FST	Finite State Machine
FTP	File Transfer Protocol
GSM	Global system for Mobile communication
GTP	GPRS Tunneling Protocol
GUI	Graphical User Interface
HSS	Home Subscribe Service
HTTP	Hypertext Transfer Protocol
ICMP	Internet Control Message Protocol
IDE	Integrated Development Environment
IGMP	Internet Group Message Protocol

IMTS	Improved Mobile Telephone Service
ISO	International Standard Organization
I-TCP	Indirect TCP
LTE	Long Term Evolution
METP	Mobile End Transmission Protocol
MME	Mobile Management Entity
MSC	Mobile Switch Center
MSR	Mobile Support Router
MSS	Maximum Segment Size
M-TCP	Mobile TCP
MTS	Mobile Telephone Service
NCP	Network Control Protocol
NED	Network Description Programming language
ns-2	Network Simulator 2
ns-3	Network Simulator 3
OFDMA	Orthogonal-Frequency Division Multiple Access
OPNET	Optimized Network Engineering Tools
OSI	Open System Interconnection
OTCL	Object-oriented Tool Command Language
PDCP	Protocol and Packet Data Convergence Protocol
PER	Packet Error Rate
P-GW	Packet Gateway
PSTN	Packet Switch Telephone Network
RARP	Reserve Address Resolution Protocol
REAL	Realistic and Large
RFC	Request For Comment

RLC	Radio Link Control
RTO	Retransmission Timeout
RTT	Round Trip Time
SACK	Selective Acknowledgment
SCG	Close Subscribe Group
SCTP	Stream Control Transmission Protocol
S-GW	Server Gateway
SIM	Subscribe Identity Module
SMART	Simple Method to Aid Retransmission
SMSS	Sender Maximum Segment Size
SNMP	Simple Network Management Protocol
ssthresh	Slow Start Threshold
TCP	Transmission Control Protocol
TCP/IP	Transmission Control Protocol/Internet Protocol
TCPW	TCP Westwood
TE	Terminal Equipment
TULIP	Transport Unaware Link Improvement Protocol
UDP	User Data Protocol
UE	User Equipment
UICC	Universal Integrated Circuit Card
UMTS	Universal Mobile Telephone Service
USIM	Universal SIM
WiMAX	Worldwide Interoperability for Microwave Access
WTCP	Wireless TCP
ZWA	Zero Window Acknowledgment
ZWP	Zero Window Probe