Οικονομικό Πανεπιστήμιο Αθηνών
Τμήμα Πληροφορικής

Ευφυή Κινητά Δίκτυα: Mobile Transport Layer

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Congestion control in mobile & wireless networks

- TCP assumes congestion if packets dropped ⇒ typically wrong in mobile & wireless networks
  - Unchanged TCP performance degrades severely
- Packet loss in mobile & wireless networks can be due to
  - Wireless transmission errors
  - Mobility when node moves from one network attachment point to another while there are still packets in transit

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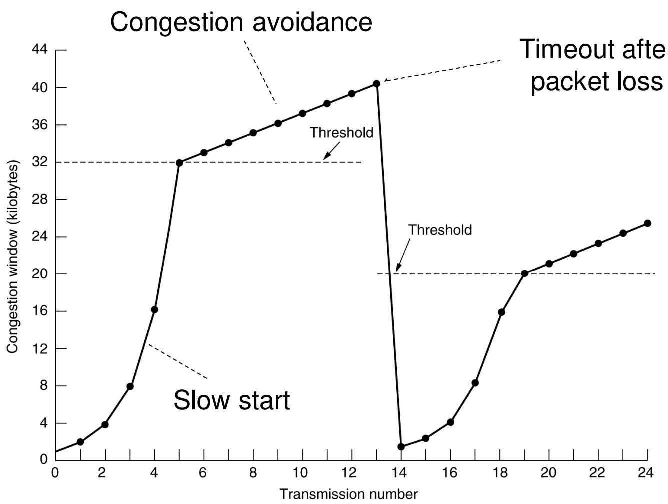
Congestion control in mobile & wireless networks (cont.)

- TCP reacts to packet loss with reduction of congestion window
- Correct reaction when loss is due to link congestion
  - Rate of packets entering a queue is larger than rate at which packets leave queue
- May not be correct reaction when loss is due to wireless transmission errors:
  - physical layer transmission rate should be reduced (or transmission power increased)

TCP congestion control



Solution

- How to solve performance degradation of TCP over wireless
  - Ideal TCP behavior: TCP retransmits packets lost due to wireless transmission errors without taking congestion control actions
  - Ideal network behavior: hide transmission errors from TCP sender
    - Includes avoiding errors and indirect effects such as increase of delay & delay variation
  - Approaches try to achieve one of the above
    - Ideal behavior cannot be realized in practise

Alternative approaches

- Link layer approach
  - TCP-unaware and TCP-aware
- Split connection approach
  - Split end-to-end TCP connection
- End-to-end approach
  - Explicit notification schemes

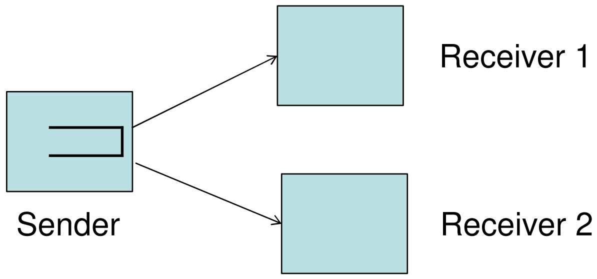
Link layer mechanisms

- Forward Error Correction
  - Corrects small number of errors
  - Overhead incurred even when no errors occur
- Link layer retransmission
  - Overhead incurred only when errors occur
- Above mechanisms are TCP-unaware

Link layer retransmission issues

- When to retransmit frame?
  - Link layer retransmission timeout
  - Negative acknowledgment
- Maximum number of retransmissions?
  - Finite or infinite
- Retransmissions hide losses by influence end-to-end delay
  - May have impact on TCP's RTT estimation
- Should link layer deliver packet in order or as they arrive?

Link layer retransmission issues (cont.)

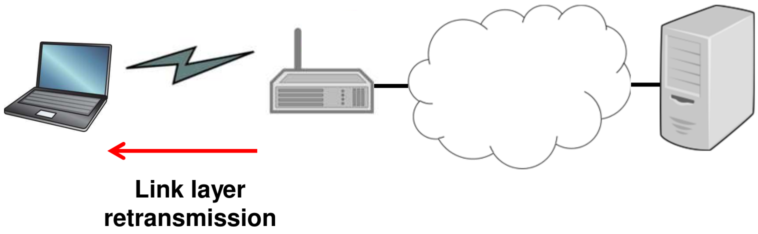


- Can cause head of line blocking in sender queue
- Can cause congestion losses (queue overflow)

TCP-aware link layer

- Snoop protocol, H. Balakrishnan et al. 1996
- Transparent to TCP
  - End-to-end semantics not changed
- Buffers packets at access point to do local retransmission in case of packet loss

TCP-aware link layer (cont.)



- Access point
  - snoops packets in both direction to identify acks
  - buffers packets until ack identified
  - retransmits packets in case of timeout or dupacks

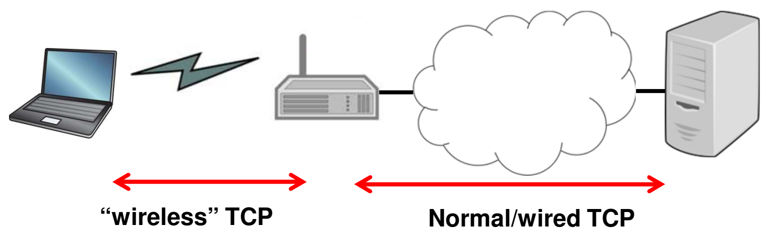
TCP-aware link layer features

- Access point maintains soft state
  - Can recover if snoop agent crashes
- Recovers errors only in direction from access point to mobile
- Avoids retransmission at TCP sender by dropping dupacks from mobile
- Cannot be applied if TCP data and acks traverse different path (asymmetric)
- If RTT over wireless link small $\Rightarrow$ simple (TCP-unaware) link layer retransmission performs equally well

Split connection approach

- Indirect TCP, B.R. Badrinath et al. 1995
- End-to-end TCP connection broken into one connection over wired part and one over wireless part of path
  - Two parts if there is one wireless link which is first or last hop
- TCP over wireless link can be modified
  - However, benefits can exist even with unmodified TCP due to smaller RTT

Split connection approach (cont.)



- Agent at access point acts as proxy
  - Local retransmission in case of wireless losses
- End-to-end semantics broken
  - Ack at fixed TCP sender does not mean mobile received packet
  - What happens if agent at access point crashes?

Split connection approach (cont.)

- Access point maintains hard state
  - Unlike Snoop approach where access point maintains soft state
- Split connection allows independent congestion control over two parts
  - Different congestion/error control protocols, timeouts, etc
- Increased latency due to copying of packets across two connections

Explicit notification schemes

- Approximate ideal behavior: TCP should retransmits packet in case of errors without taking congestion control actions
- TCP sender needs to know cause of loss
  - wireless node identifies that loss is due to transmission error and notifies TCP sender
- Variations
  - Who sends explicit notification and when
  - What sender does when notification received

Explicit Loss Notification (ELN)

- H. Balakrishnan et al. 1998
- Mobile node is TCP sender
- Access point tracks holes in packet sequence received from mobile sender
- When dupack received from receiver, access point compares seq # with recorded holes
  - In case of match sets ELN bit in dupack
- If mobile sender receives dupack with ELN bit set: retransmits packet but does not reduce congestion window

Observations

- A lot of investigation and many techniques have been proposed
  - Improvements for specific cases
- Link layer retransmissions can improve performance without being TCP-aware
  - For low delay wireless links
- End-to-end techniques that do not require TCP specific support from lower layers, e.g. TCP Selective ACKnowledgements
- Link layer techniques achieve higher gains compared to end-to-end schemes
  - For low delay wireless links

Impact of mobility on TCP

- Handoff occurs when a mobile starts communicating with new base station (or foreign agent in case of mobile IP)
- Link layer handoffs
  - No change of IP address
  - TCP will not be aware of handoff
  - Link layer handles reliability
  - Increased packet delay
- Network layer handoff
  - Need mobile IP
  - Packets can be lost while mobile moves to new base station

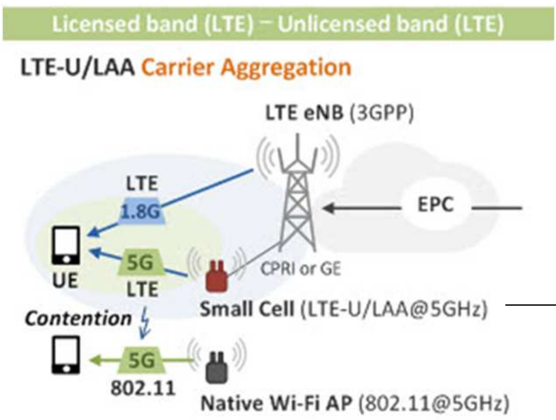
Improving TCP during mobility

- Invoke fast retransmit after handoff
- Buffer packets at base station (or foreign agent in case of mobile IP)
  - Forward packets to new base station
- Use multicast
  - Send packets destined to mobile to current base station and base stations mobile is likely to visit next
  - Incurs throughput & buffering overhead

LTE aggregation and MultiPath TCP

- MultiPath TCP (MPTCP): more than one simultaneous flows from source to destination over different paths
- 3GPP Release 13 supports co-existence and aggregation of licensed and unlicensed bands
  - Licensed Assisted Access (LAA)
  - enhanced-Licensed Assisted Access (eLAA) in Rel. 14
  - Further Enhanced LAA (feLAA) in Rel. 15
- 3GPP Release 15 (first 5G release) defines Dual Connectivity (DC) allowing simultaneous LTE and 5G NR connections

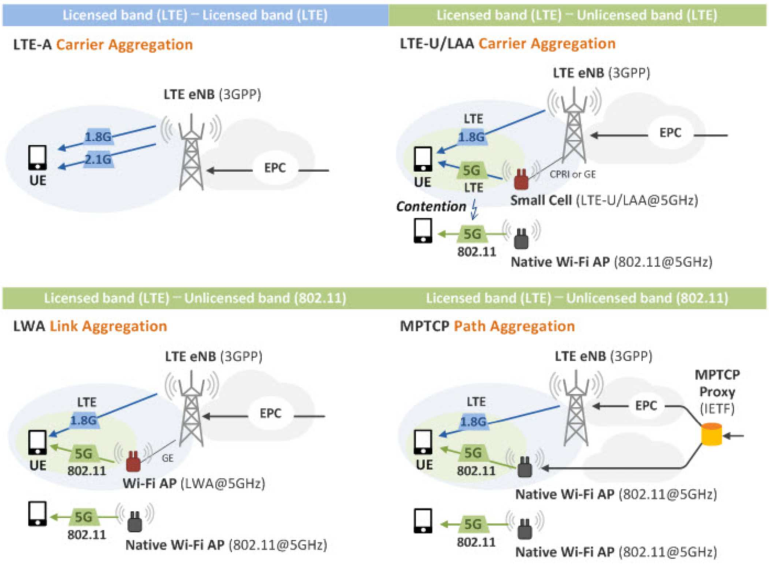
LAA: Licensed Assisted Access



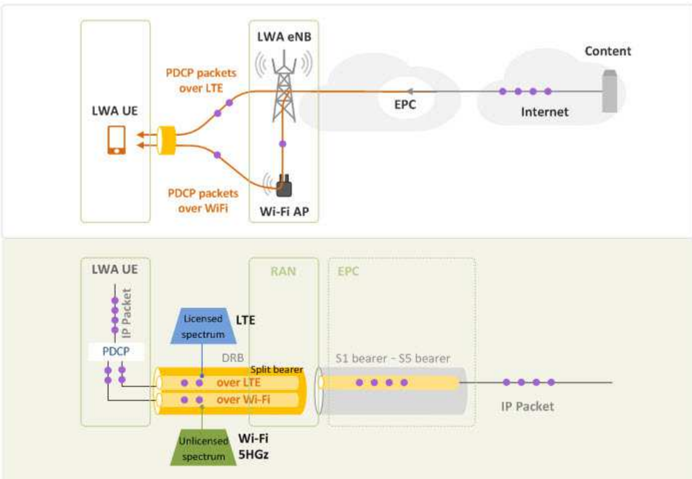
Fair access can be achieved with Listen Before Talk (LBT)

source: www.netmanias.com

LTE aggregation solutions



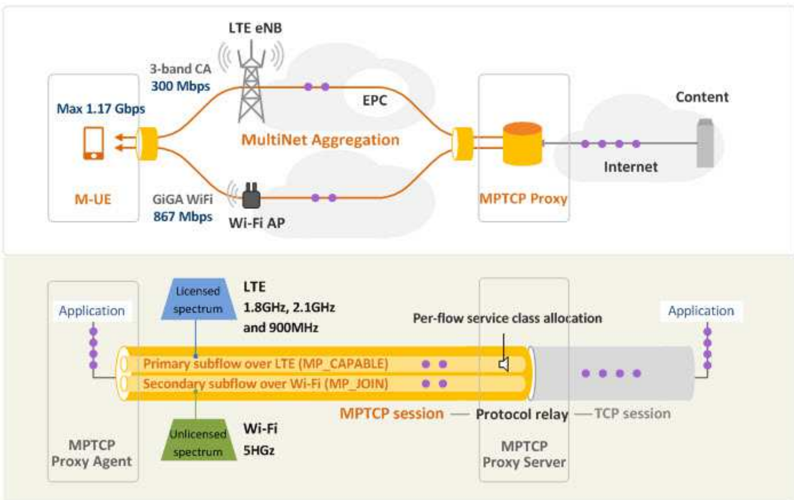
LTE-WiFi Link Aggregation (LWA)



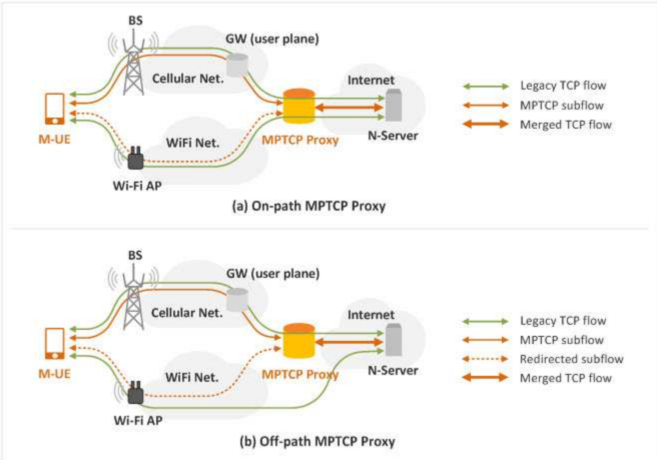
MPTCP and mmWave

- mmWave channel fluctuations larger than LTE (<6 GHz)
- MAC layer retransmissions are necessary, as in lower frequency bands
- MultiPath TCP (MPTCP)
  - For small distances using multiple mmWave links can achieve higher throughput
  - For larger distances using LTE as secondary link achieves higher throughput compared to using two mmWave links
  - Sending ACKs on LTE and data on mmWave does not improve throughput

MPTCP proxy



MPTCP proxy modes



Comparison of aggregation technologies

Table 2. Comparison of aggregation technologies (blue: 5 GHz, yellow: LTE Band, character: MAC/PHY)

	LTE-A CA	LTE-U/LAA	LWA	MPTCP Proxy
Aggregation	LTE LTE LTE	LTE LTE LTE	LTE LTE 802.11	LTE LTE 802.11
Standardization	3GPP	LTE-U Forum/3GPP	3GPP	IETF
Leading WG	RAN WG1	RAN WG1	RAN WG2	MPTCP WG
Release	Release 10	LAA: Release 13	Release 13	RFC 6824 etc.
Protocol layer	LTE L2 (MAC)	LTE L2 (MAC)	LTE L2 (PDCP)	TCP (MPTCP)
LTE spectrum cost	LTE spectrum cost	No additional spectrum cost	No additional spectrum cost	No additional spectrum cost
Access network cost	High (New eNB/RRH with new LTE band)	High (New LTE small cell with LTE-U/LAA@5 GHz)	Medium (New small cell: LWA-aware WiFi AP)	None (Use Existing ubiquitous WiFi AP)
New HW support	-	UE and eNB (5 GHz LTE)	-	-
New device function	-	5 GHz LTE	PDCP	MPTCP (OS)
Network element	-	LTE-U/LAA small cell	LWA eNB, LWA-aware WiFi AP	MPTCP Proxy
LTE-WiFi coexistence problem	-	Contention Problem	-	-
Regulation problem	Globally harmonized	Global hamonization required	-	-
Monetization (OTT, CSP)	-	-	-	B2B revenue opportunity