Transport layer issues

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Contents

- Issues in designing a transport layer protocol for ad hoc wireless networks
- Problems with the traditional TCP in ad hoc wireless networks
- TCP based protocols for ad hoc wireless networks
- Other transport layer protocols for ad hoc wireless networks

Issues in designing a transport layer protocol for ad hoc networks

- Induced traffic. Traffic sent by other nodes affects throughput
- Induced throughput unfairness. Some MAC protocols that are used for wireless networks may add throughput unfairness to the transport layer as well
- Separation of congestion control, reliability and flow control. The performance may improve if these three are handled separately

Issues in designing a transport layer protocol for ad hoc networks

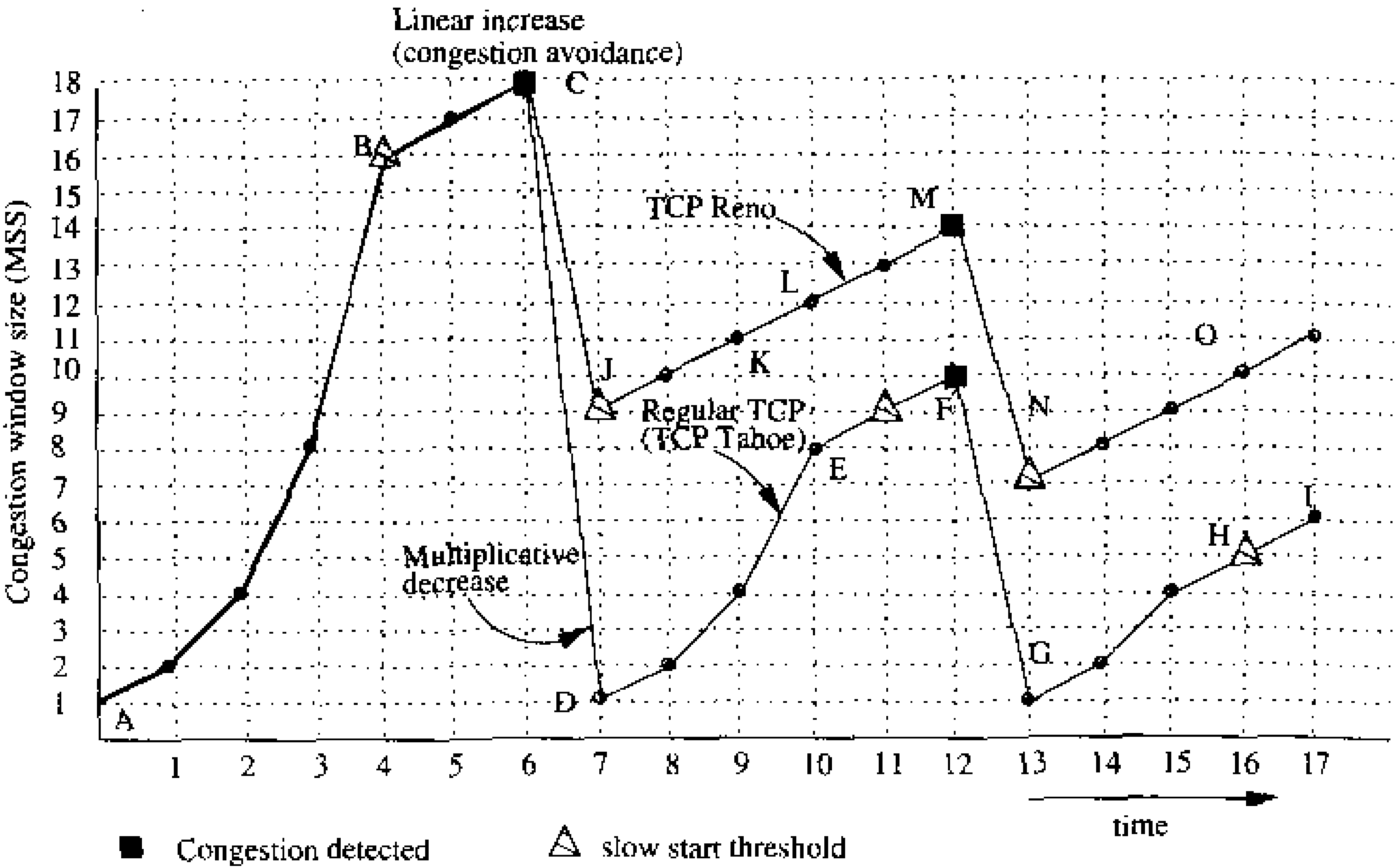
- Misinterpretation of congestion. Bit error rates are much higher in wireless networks, thus traditional methods like measuring packet loss are unsuitable for congestion detection
- Decoupled transport layer. In wired networks transport layer is decoupled from lower layers. In wireless networks cross-layer interaction would help the transport layer protocol to adapt to the changes in the network
- Power and bandwidth constraints
- Dynamic topology

Problems with the traditional TCP in ad hoc networks: background

- TCP is a reliable, end-to-end transport protocol
- TCP is responsible for handling congestion control, flow control, in-order delivery of packets, and reliable transportation of packets
- Congestion control in TCP
  - TCP regulates the number of packets sent to the network by changing the size of the congestion window
  - In the beginning of the session, the size of the congestion window is one maximum segment size (MSS)

Problems with the traditional TCP in ad hoc networks: background

- If an acknowledgment (ACK) is received during the retransmission timeout period (RTO), size of the congestion window is doubled
  - Doubling the size of congestion window continues until the size reaches slow-start threshold. Afterwards, size of the window increases linearly, by one MSS for every received ACK
- If the ACK is not received, packet loss is assumed and congestion control is initiated
  - Slow-start threshold is halved
  - Size of the congestion window is set to one MSS

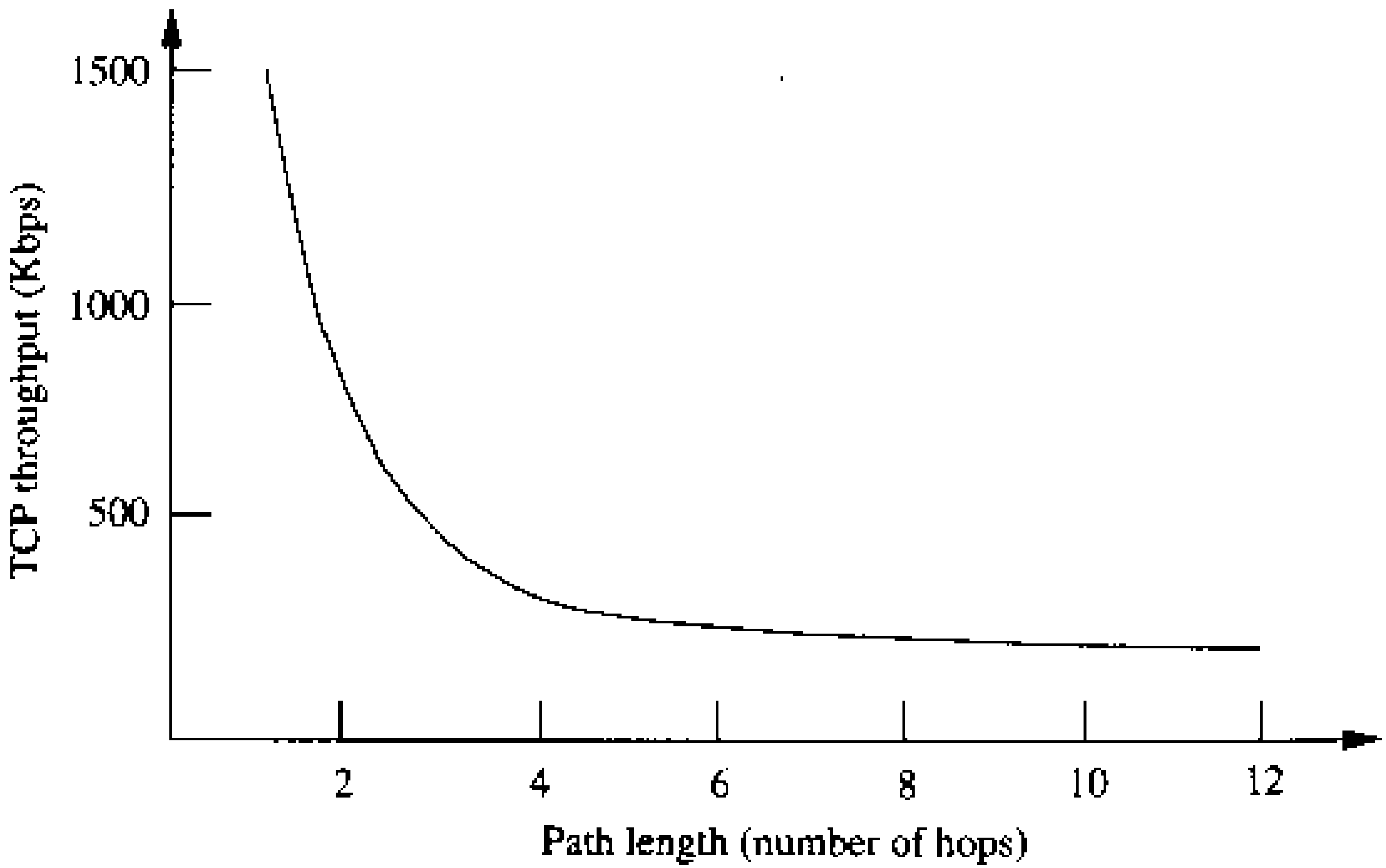

Linear increase
(congestion avoidance)
Congestion window size (MSS)
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
TCP Reno
Regular TCP
(TCP Tahoe)
Multiplicative
decrease
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
time
Congestion detected
slow start threshold

Problems with the traditional TCP in ad hoc networks

- Congestion handling is the biggest single issue in the traditional TCP
  - In ad hoc networks, packet loss can occur frequently for several reasons
    - Transmission errors
    - Path breaks
- When packet loss occurs, TCP invokes congestion control mechanism which significantly decreases the throughput
  - If packet loss occurs often, size of the congestion window stays low most of the time

Problems with the traditional TCP in ad hoc networks

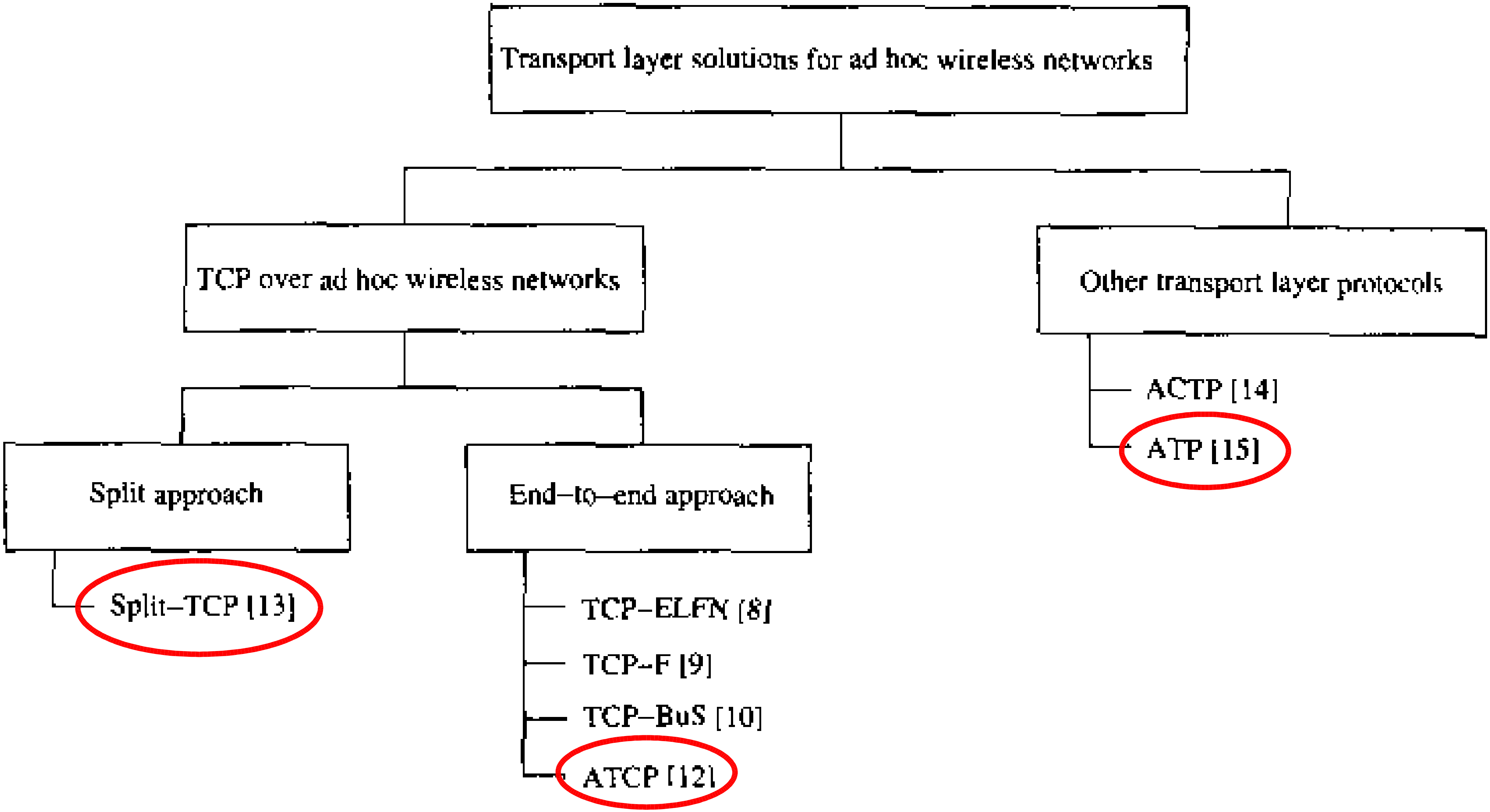
- Effect of the path length on TCP throughput (link break probability 10% per link)



Problems with the traditional TCP in ad hoc networks

- After route reconfiguration, new route may accept higher throughput. However, TCP does not take this into account
- ACKs consume very little of bandwidth in wired networks. However in IEEE 802.11 wireless network, every ACK requires RTS-CTS-Data-ACK exchange, which might lead to the 70 byte overhead
- TCP does not work well with multipath routing since multipath routing may produce large amount of out-of-order packets

Transport layer solutions for ad hoc wireless networks

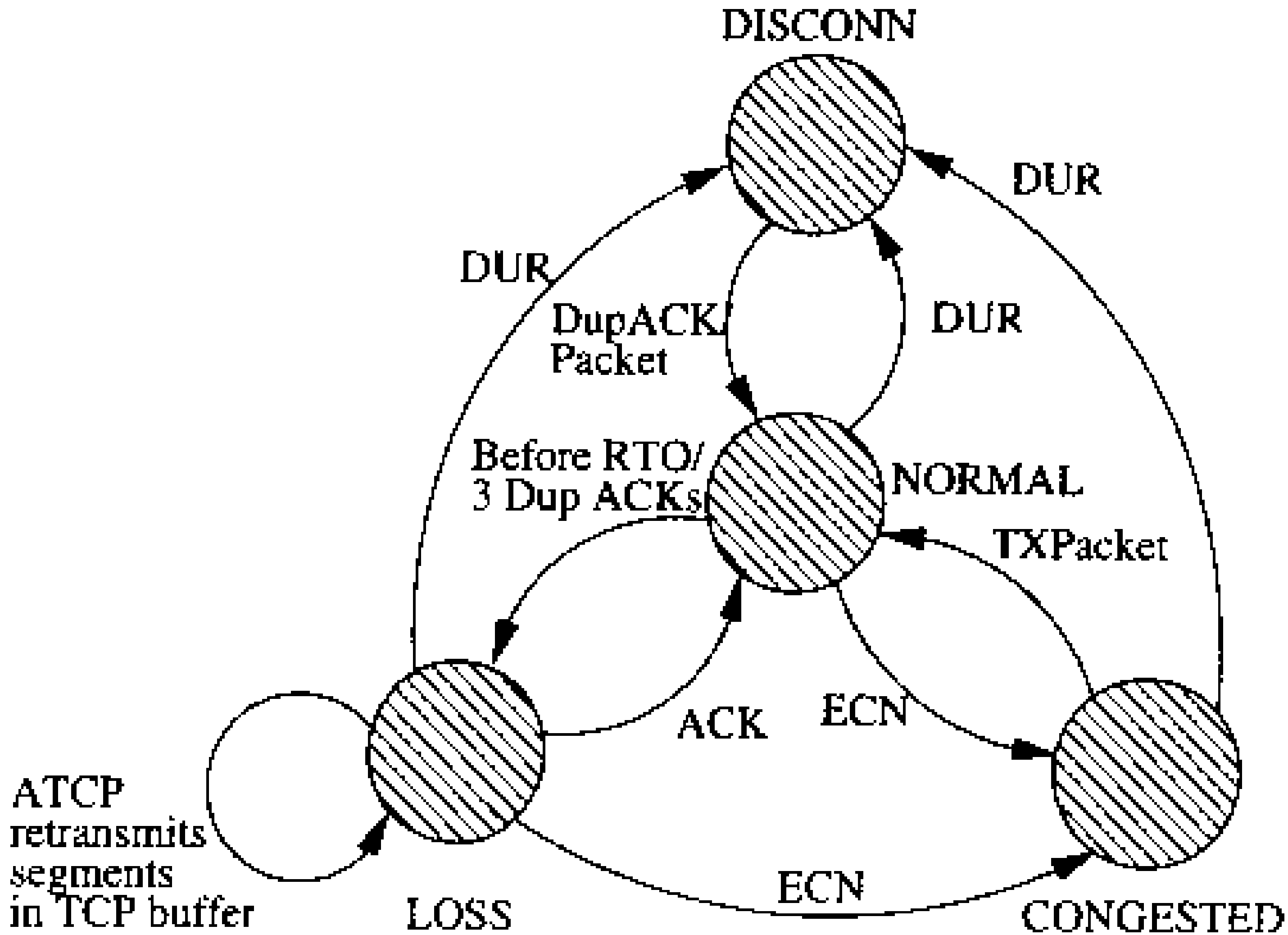


TCP based protocols for ad hoc networks: Ad hoc TCP

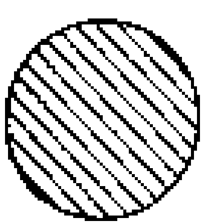
- Ad hoc TCP (ATCP) relies on a network feedback mechanism to be aware of the status of the network path
  - Explicit congestion notification (ECN) flags and destination unreachable (DUR) messages are used for providing information to the sender about current network conditions
- If there is a packet loss, ATCP retransmits missing packets without invoking a congestion control

TCP based protocols for ad hoc networks: Ad hoc TCP

- ATCP detects network congestion from the ECN flag. When the network congestion is detected, ATCP lets TCP invoke a congestion control
- ATCP detects route failures from DUR messages that are sent by other nodes in the network
  - In this case the ATCP changes to the disconnect state and the size of congestion window is set to one. Thus, when the connection is returned, TCP will determine optimal congestion window size



(b) State transition diagram for the ATCP sender



TCP sender in persist state

DUR – Receive destination unreachable

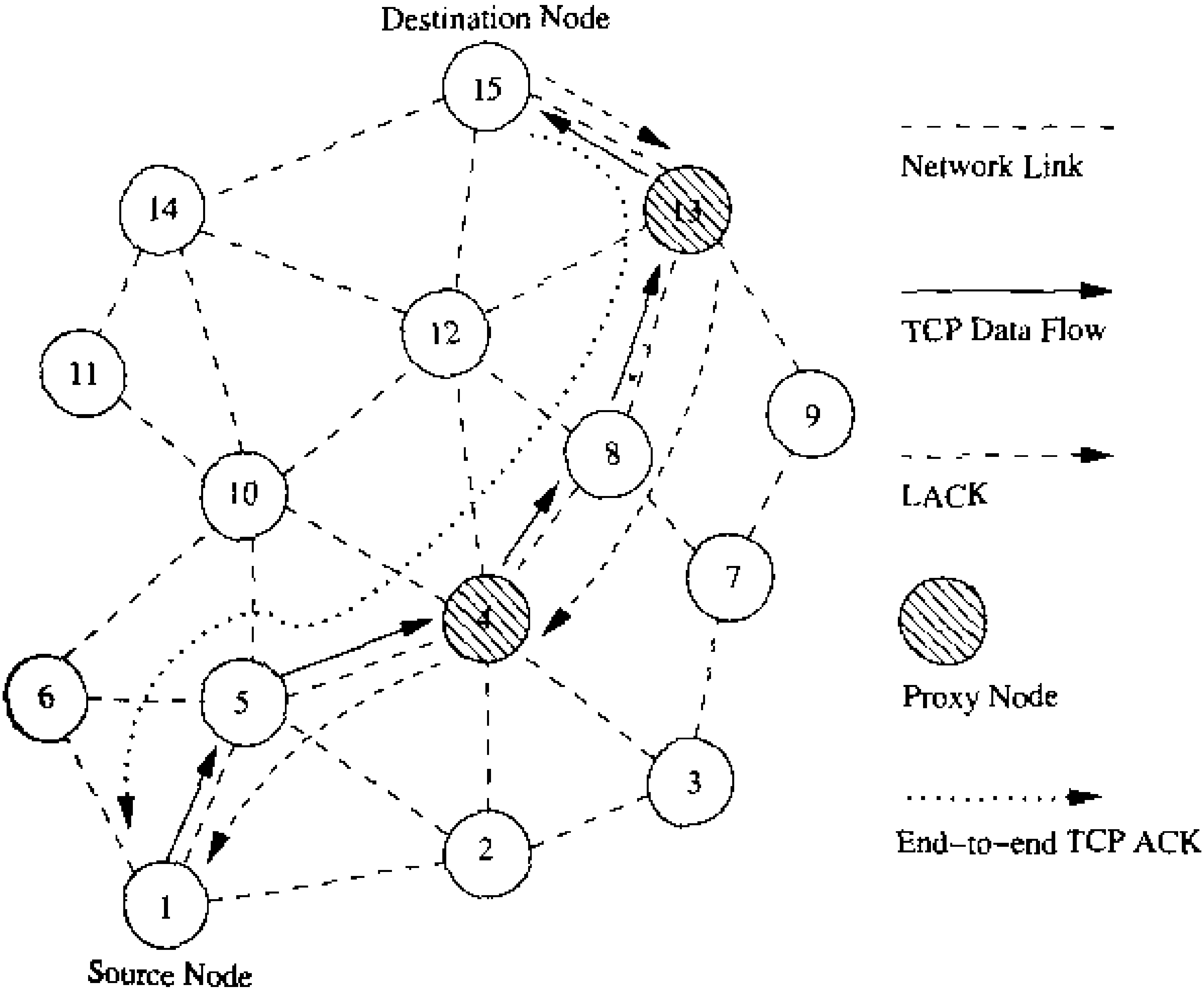
TXPacket – TCP transmits a packet

TCP based protocols for ad hoc networks: Ad hoc TCP

- The ATCP is implemented as a layer between the TCP layer and the network layer
  - ATCP support is only needed for the sender
- Advantages
  - Compatible with a traditional TCP
  - Feasible and efficient solution for improving throughput in ad hoc wireless networks
- Disadvantages
  - Dependency on the network layer protocols to detect route changes and partitions
  - Addition of the ATCP layer to the TCP/IP protocol stack

TCP based protocols for ad hoc networks: Split TCP

- With traditional TCP, throughput rabidly degrades when the path length is increased
  - This might lead to unfairness among TCP session, session with a short path length will achieve higher throughput
- Split TCP provides solution to this problem by splitting the transport layer objectives into congestion control and end-to-end reliability
- A long TCP connection is split into series of short connections that terminate at proxy nodes


Destination Node
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
Source Node
Network Link
TCP Data Flow
LACK
Proxy Node
End-to-end TCP ACK

TCP based protocols for ad hoc networks: Split TCP

- Upon receiving the packet, the proxy node sends a local acknowledgment (LACK) to the source (or the previous proxy)
  - The previous proxy clears own buffer after receiving LACK
- When the packet reach destination, destination node sends end-to-end ACK to the source node
  - The source node clears own buffer only after receiving end-to-end ACK
  - The size of the congestion window at the source node is determined by LACKs

TCP based protocols for ad hoc networks: Split TCP

- Advantages
  - Improved throughput (because of shorter paths)
  - Improved throughput fairness
  - Lessened impact of mobility
- Disadvantages
  - Requires modification to the TCP protocol
  - End-to-end connection handling is violated, might cause problems with some IP encryption schemes
  - Proxy nodes can fail and this will decrease throughput

Other transport layer protocols: Ad hoc transport protocol

- Ad hoc transport protocol (ATP) is specifically designed for ad hoc wireless networks, it is not based on TCP
- Major differences to TCP
  - Coordination amount multiple layers
  - Rate based transmission
  - Decoupling congestion control and reliability
  - Assisted congestion control

Other transport layer protocols: Ad hoc transport protocol

- ATP uses information from lower layers for
  - Estimating the initial transmission rate
  - Detection, avoidance and control of congestion
  - Detection of path breaks
- ATP uses a timer-based transmission where the rate is dependent on the congestion in the network
  - Network congestion information is obtained from intermediate nodes while flow control and reliability information is obtained from the ATP receiver

Other transport layer protocols: Ad hoc transport protocol

- Intermediate nodes attach congestion information in every ATP packet and the ATP receiver collates and includes it in the next ACK packet
- During the startup process, ATP sender sends a probe packet to which the intermediate nodes attach congestion information, ATP receiver then sends this information back to the ATP sender in ACK packet
  - To reduce control overhead, connection request and associated ACK packets are used as probe packets

Other transport layer protocols: Ad hoc transport protocol

- If the ATP sender has not received ACK packets for two feedback periods, it will significantly decrease the transmission rate
  - After a third such period, connection is assumed to be lost and the ATP sender goes to the connection initiation phase
- ATP increases the transmission rate gradually, in order to avoid unnecessary fluctuations
- When a path break occurs, the network layer sends an explicit link failure notification (ELFN) packet to the ATP sender
  - ATP sender goes to the connection initiation phase

Other transport layer protocols: Ad hoc transport protocol

- Advantages
  - Improved performance, ATP does not suffer from congestion window fluctuations
  - Decoupling of the congestion control and reliability mechanisms
- Disadvantage
  - Does not work with TCP
  - In large ad hoc wireless networks, per-flow timer used at ATP sender may become a bottleneck in mobile nodes

Conclusions

- Designing a good transport layer protocol for wireless ad hoc networks is a very difficult task
  - Performance vs. compatibility with TCP and routing protocols
- There exists several transport layer protocols for wireless ad hoc networks, each with their own advantages and disadvantages