MAC Protocols for Mobile Ad Hoc Networks

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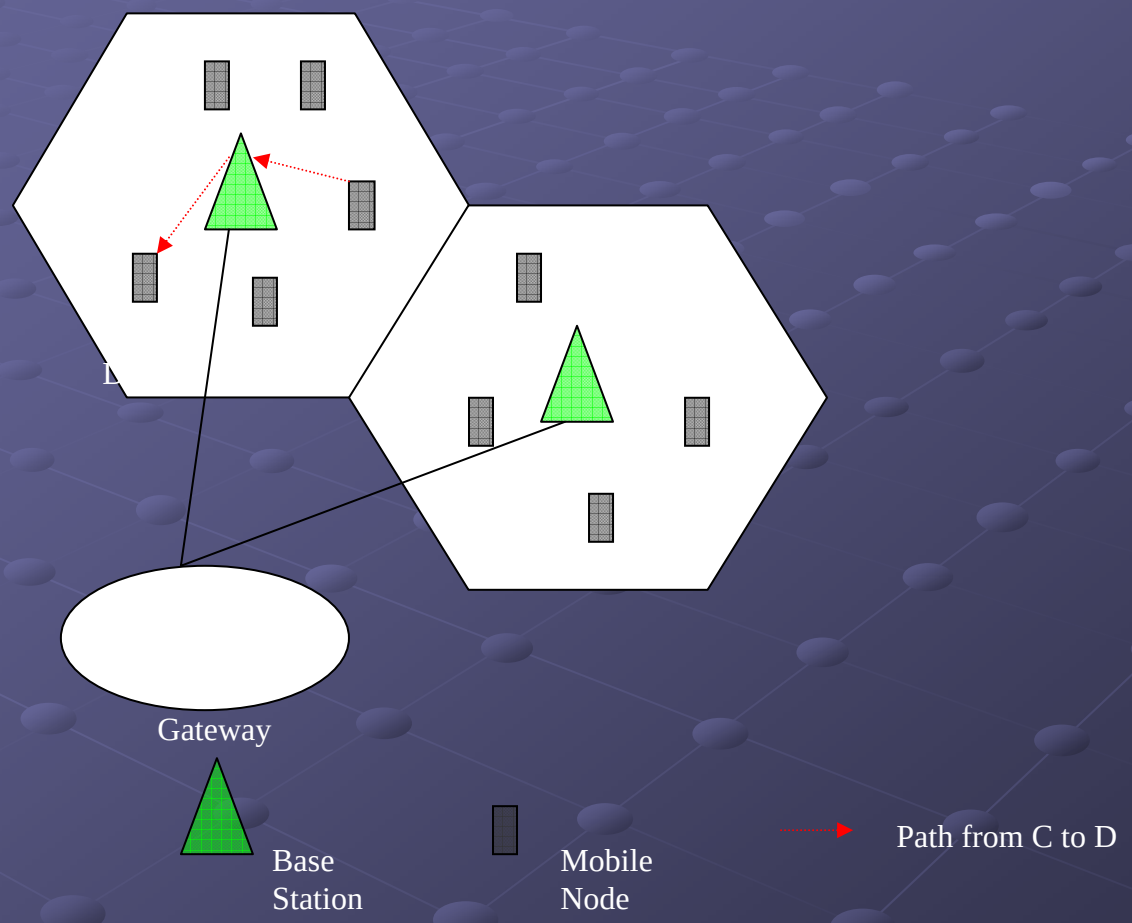
Problem Statement

- Mobile Ad hoc Networks (MANETs) attract much research interest
- Challenges of MAC algorithm for MANETS
- Issues of Spread Spectrum MAC in MANETs
  - Code assignment; Collision avoidance;
  - Efficiency; High peak rate

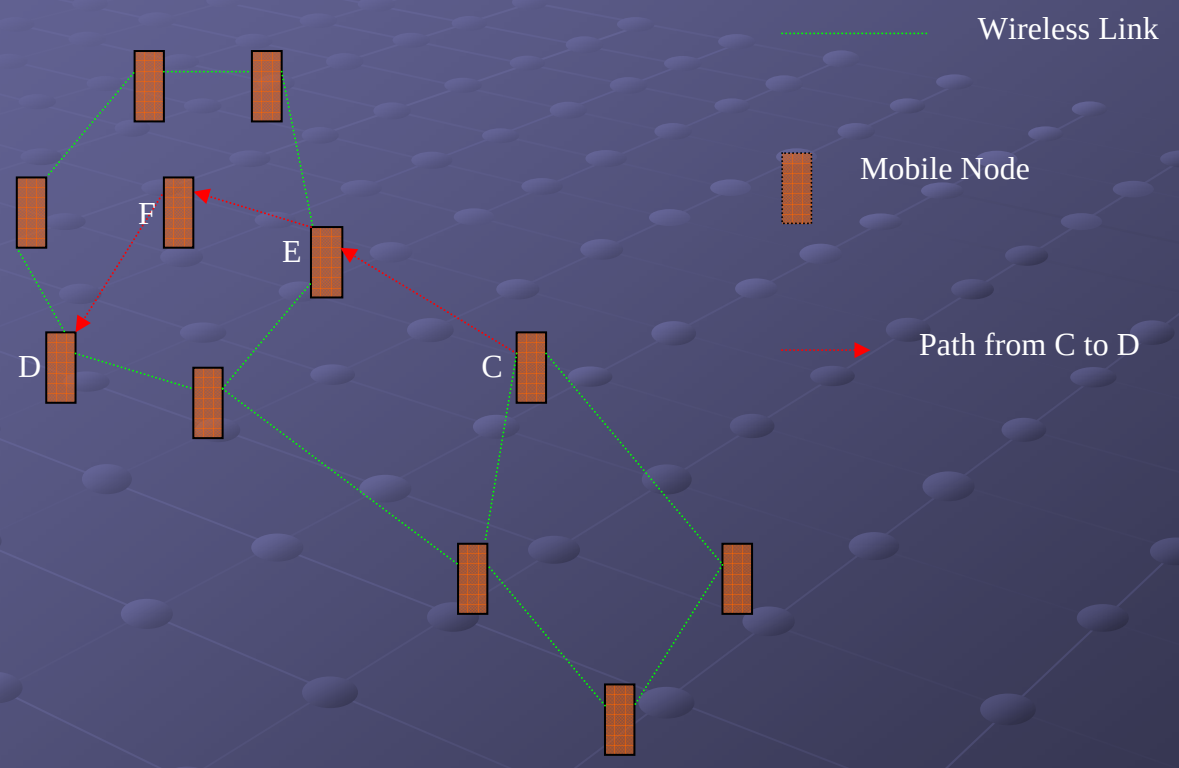
Objectives

- To review MAC designs for MANETs
- To analyze issues of Spread Spectrum MAC for MANETs
- To propose a Dynamic-Rate-with-Collision-Avoidance MAC Protocol for MANETs
- To perform theoretic and numerical analysis of its performance in MANET

Traditional Cellular Networks



Mobile Ad Hoc Wireless Network



MANETs (cont.)

- No support of any fixed infrastructure or centralized administration;
- Completely distributed;
- Multi-hop radio relaying.

Potential Users of MANETs

- The military;
- Public safety;
- Homeland security;
- Commercial wireless organizations.

Challenges for MAC

- Hard to know network information without any central controller;
- Power limitation – needs multi-hop to deliver;
- Hidden and Exposed Terminals are common;
- Need to support real time applications.

Requirements for MAC

- Work properly without a central-controller.
- Take care the hidden and exposed terminal problems.
- Support real-time applications.
- Power efficiency.
- High efficiency and high throughput.

Single and Multi-channel MAC

- Single channel MAC uses all the available bandwidth as one channel and the channel is shared by a number of communication nodes located in close proximity;
- Multi-channel MAC divides bandwidth into several parts and can transmit data on each one simultaneously

Some Examples

- Single channel MAC Protocols
  - 802.11 DCF (Distributed Coordination Function) [1]
  - MACA (Medium Access/Collision Avoidance) [2]
  - MACAW (MACA-Wireless) [2]
  - MARCH (Multiple Access with ReduCed Handshake [3]
  - FAMA (Floor Acquisition Multiple Access) [4]
  - MACA-BI (MACA By Invitation) [5]
  - CSMA/CP (CSMA with collision prevention) [6]

Examples (cont.)

- Multi-channel MAC Protocols
  - BTMA (Busy Tone Multiple Access) [7]
  - DBTMA (Dual BTMA) [8]
  - MMAC (Multi-channel MAC) [9]
  - Multichannel CSMA MAC Protocol [10]
  - SNDR (Sequenced Neighbor Double Reservation) [11]
  - DCA (Dynamic Channel Assignment) [12]

Schemes to support real time applications

- Prioritized transmission
- Scheduling
- Reservation

Motivation of Spread Spectrum MAC

- Spread Spectrum technology has been used successfully in cellular networks
  - 2G: IS-95
  - 3G: CDMA2000
    WCDMA
- Available spectrum is extremely limited in

  public safety, homeland security and commercial wireless organizations
- ISM (Industrial, Scientific, and Medical) are recommended by FCC. Only Spread Spectrum (SS) RF transmissions are currently allowed in ISM bands

Issues with Spread Spectrum MAC

- PN code assignment/spreading code protocols
  - Common code
  - Transmitter-based
  - Receiver-based
  - Hybrid
- Collision avoidance
  - Primarily code collision
  - Secondary code collision

Issues of SS MAC (continued)

- Bandwidth efficiency and high peak rate
  - PN code should be allocated dynamically!
  - One example of bandwidth waste:

Research of SS MAC Protocols

- Common-Transmitter (CT) and Receiver-Transmitter (RT) MAC [13]
- Multiple Access with Collision Avoidance (MACA) with CT (MACA/CT) and MACA with RT (MACA/RT) [14]
- A rate-adaptive MAC design is given for low-power ultra-wide band ad hoc network [15]

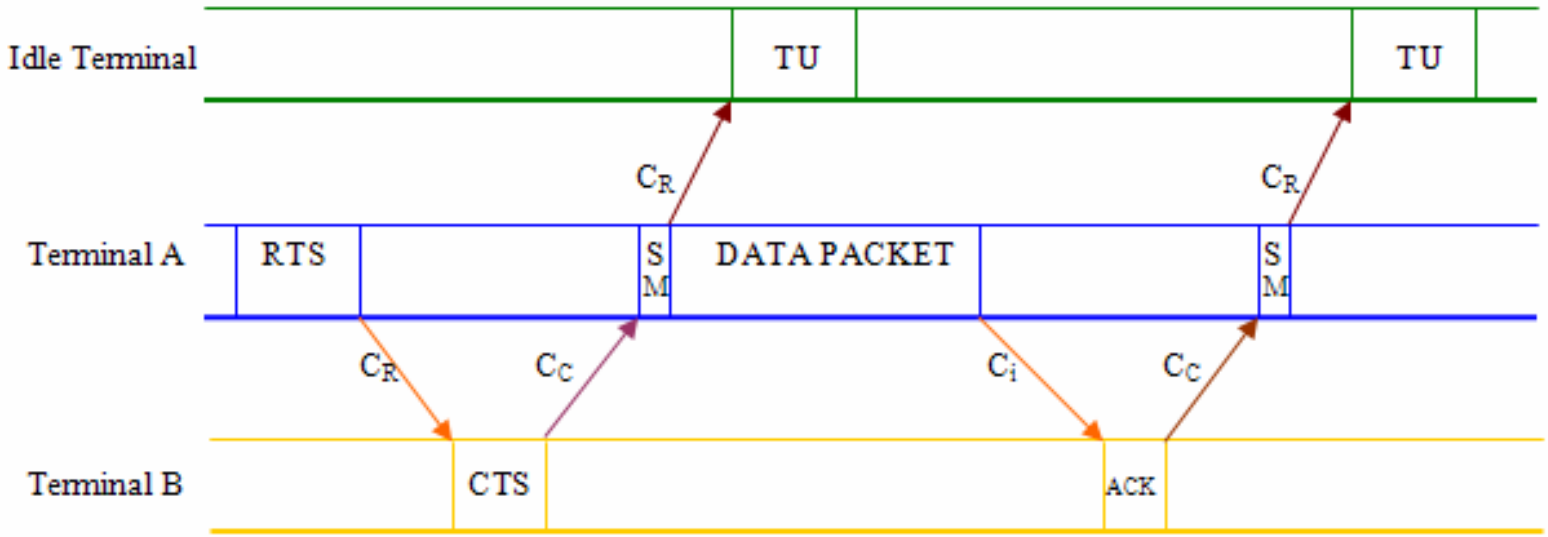
Research of SS MAC Protocols (cont.)

- None of them used Dynamic spread codes allocation!
- Correspondingly, bandwidth waste occurs when there are many idle terminals

Dynamic-Rate-with-Collision-Avoidance (DRCA)

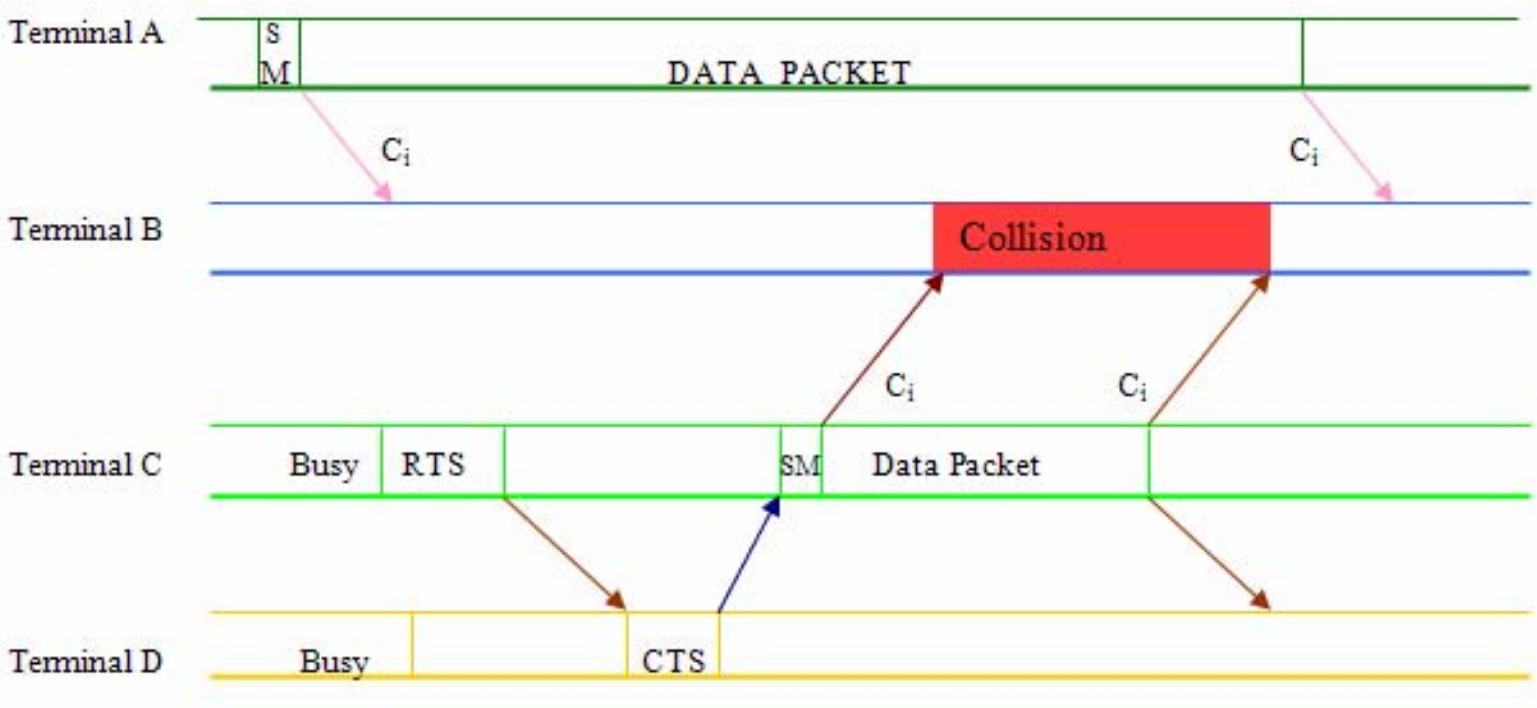
- DRCA can solve these issues
- The ideas of DRCA
  - Dynamic spread code allocation
  - “Do-Not-Use” spread code broadcast if the total number of usable spreading codes with this spreading factor is less than the total number of mobile terminals in the network

DRCA normal operation



TU: code-look-up Table Update

DRCA collision analysis



Advantages of DRCA

- Bandwidth efficiency and collision-avoidance
- Support real time applications
- Simple computation
- Hybrid spread-code protocol

BER = 10^{-6}

- Ideal channel

# of communication pairs	1	2	3	4	5	6	7	8	9	10
Spreading factor	1	12	23	34	45	57	68	79	89	101

BER = 10^{-6}

- Raleigh fading channel

# of communication pairs	1	2	3	4	5	6	7	8	9	10
Spreading factor	1	795	1589	2383	3178	3972	4766	5561	6355	7149

Performance Analysis of DRCA

Given a single-hop, slotted, mobility-free environment:

- The system can be modeled as a discrete Markov chain
- The number of communicating pairs are modeled as system state

Transition probability from state *a* to state *b*

$$P_{a,b} = (q)^{b-1}(1-q)^{a-b}\{\binom{a}{b-1}(1-q)\,p(1-p)^{M+1}$$

$$\frac{M^2+3M+2}{N-1} - \binom{a}{b} qp(1-p)^{M-1}\frac{M^2-M}{N-1} +$$

$$\binom{a}{b} q\}$$

Throughput is:

$$\gamma_d \le \sum_{r=1}^{N/2}\sum_{j=1}^{r} S_r \frac{m}{k_{rj}} = S_1 \frac{m}{k_1} + m\sum_{r=2}^{N/2} S_r r\left(\frac{1}{10^{u/10}\times(r-1)} - \frac{m_s}{m}\right)$$

- Compared with it, static PN code allocation method has:

$$\gamma_s \le \sum_{r=1}^{N/2} S_r \frac{mr}{10^{u/10}\times(N/2-1)}$$

Conclusion:

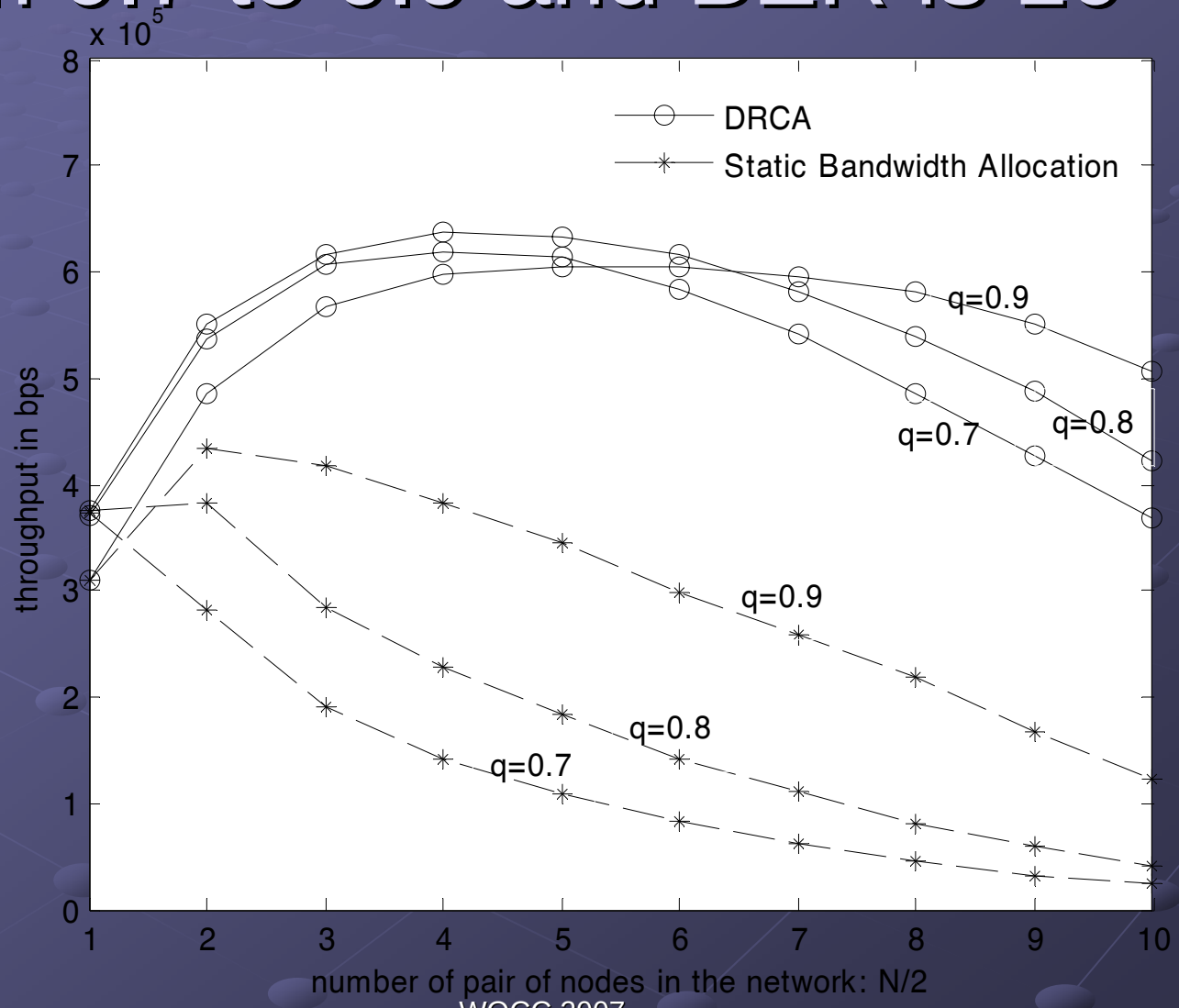
$$\gamma_d \succ \gamma_s$$

- In case of
  - Small m_s (caused by collision)
  - More than one pair of mobile terminals

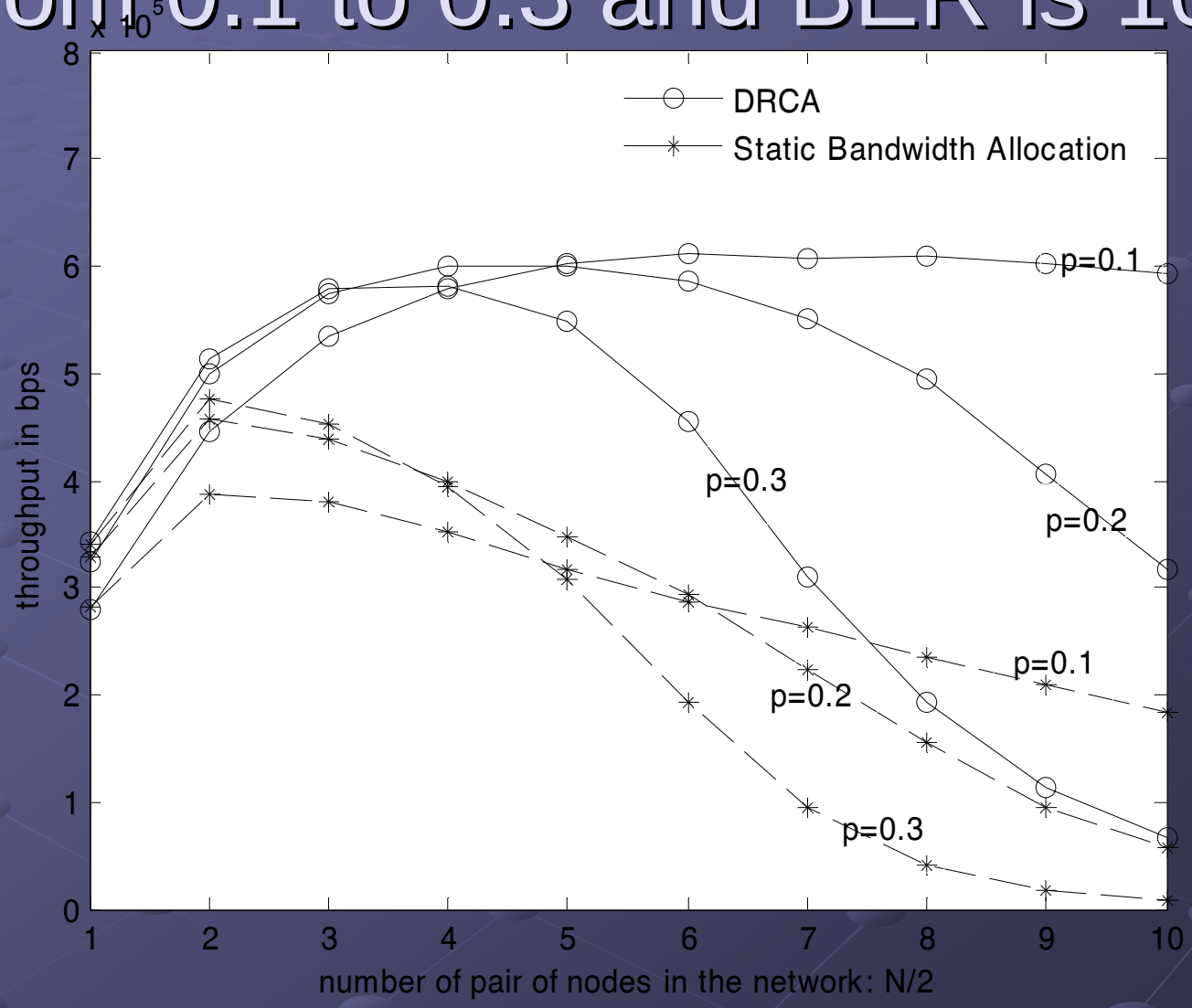
Numerical Results in a single-hop, slotted, mobility-free environment

Parameter	Value
Chip rate	6.0 Mcps
Number of terminals in the network	N= 2-20
Received signal quality target	BER = $10^{-5}/10^{-6}$
Required minimum SNR	9.5 dB/10.5 dB
Slot time	1.2 ms
Simulation time	120 ms

Throughput when *p*=0.15, *q* varies from 0.7 to 0.9 and BER is 10^{-6}



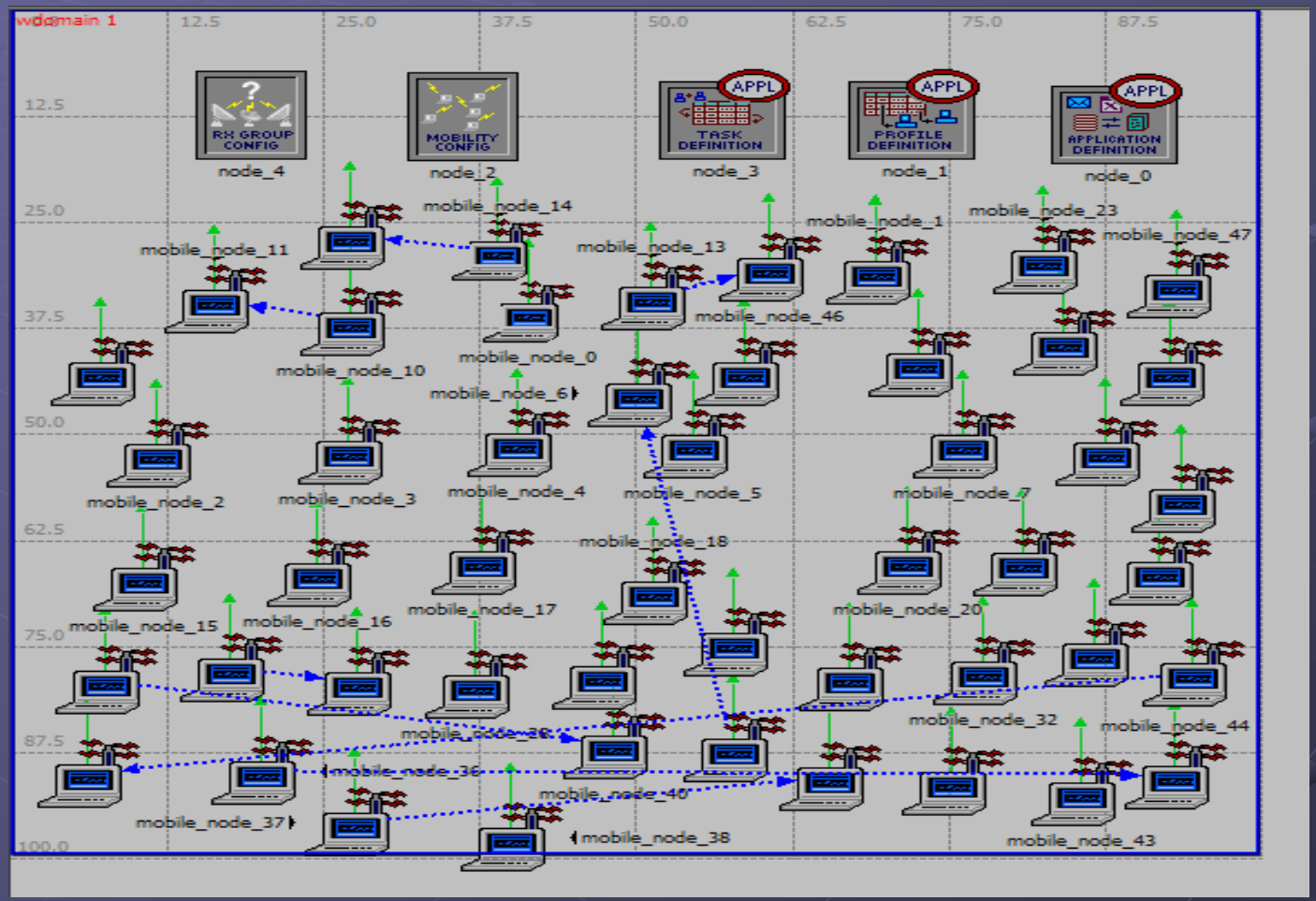
Throughput when *q*=0.9, *p* varies from 0.1 to 0.3 and BER is 10^{-6}



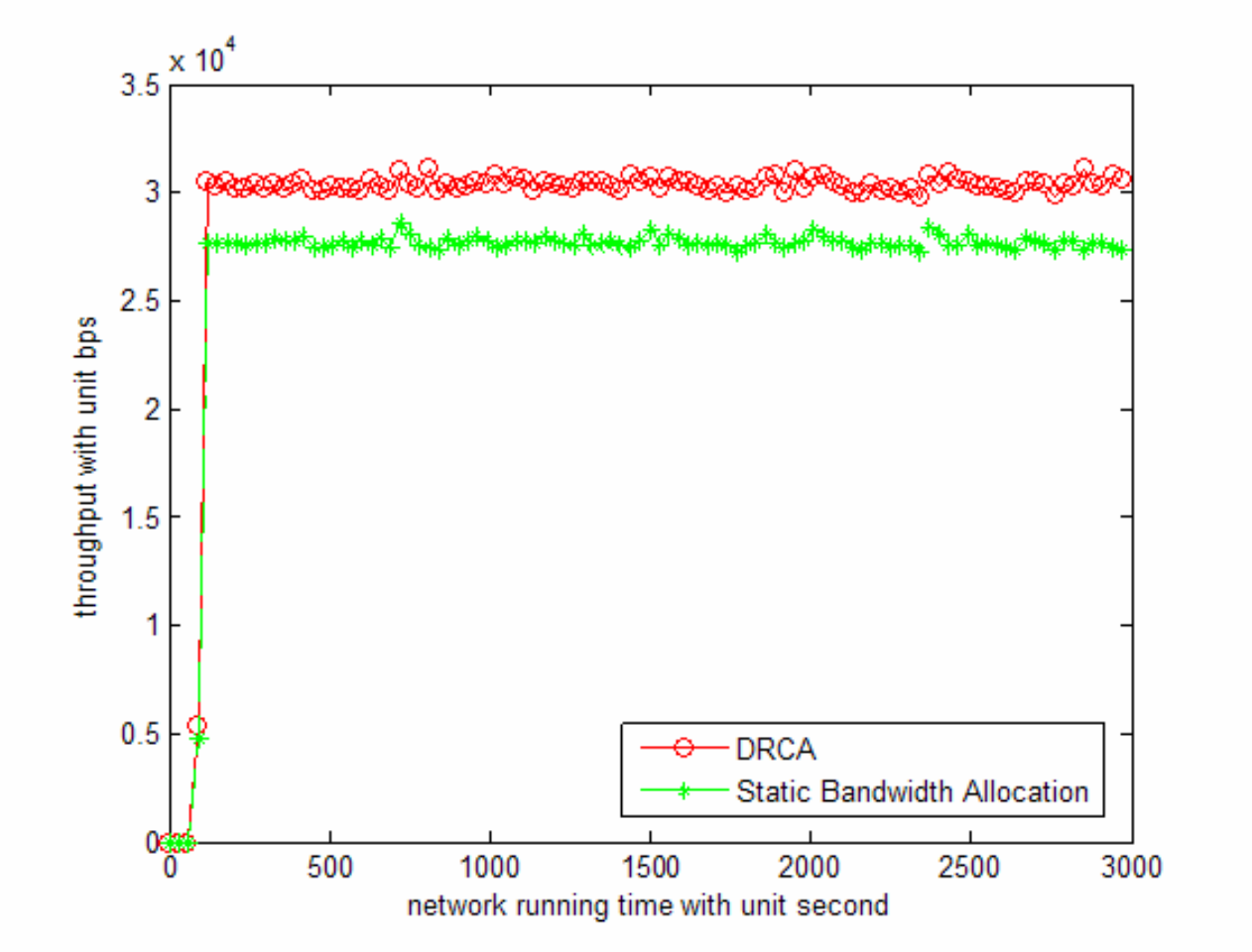
Multi-hop with Mobility

Parameter	Value
Number of mobile terminals	$N = 50$
Mobility	Random Waypoint
Routing Protocol	AODV
Traffic Patterns	Voice call; Video Call; FTP; IP Unicast
Network Layout Size	100x100 meter
Chip Rate	2.2 M cps
Received signal quality target	BER = 10^{-6}
Network running time	50 minutes

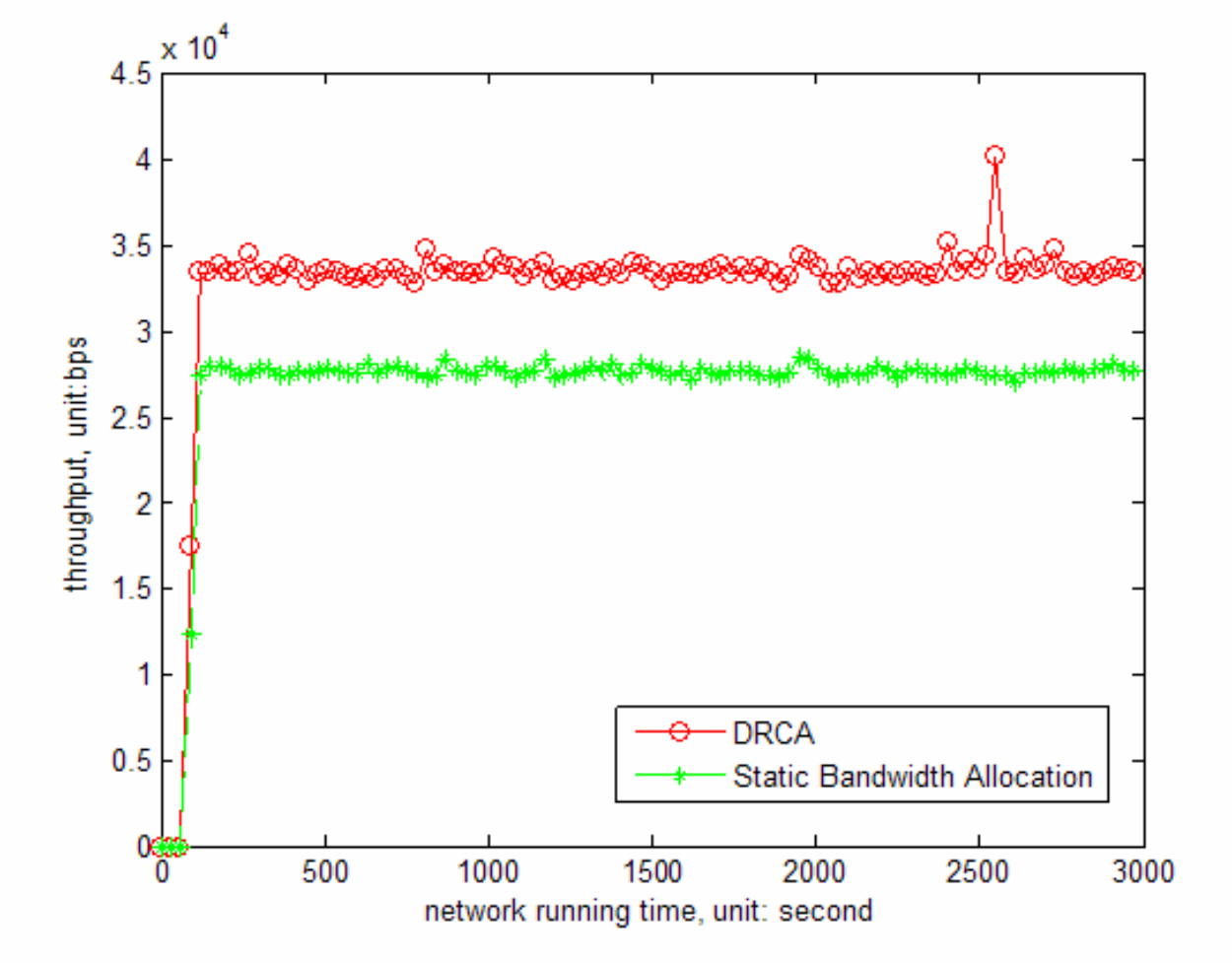
Network Layout



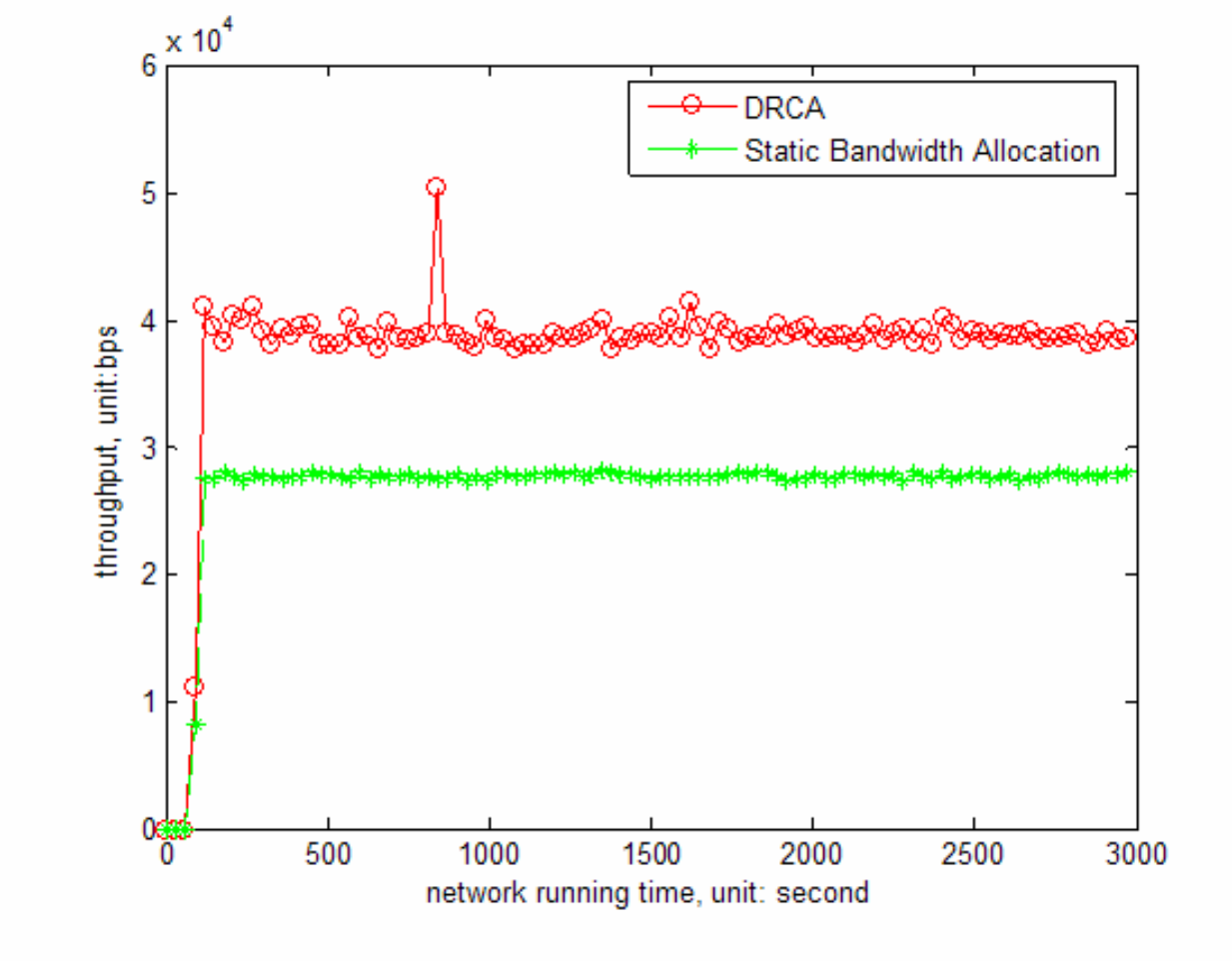
Throughput comparison : 25 pairs of active mobile terminals



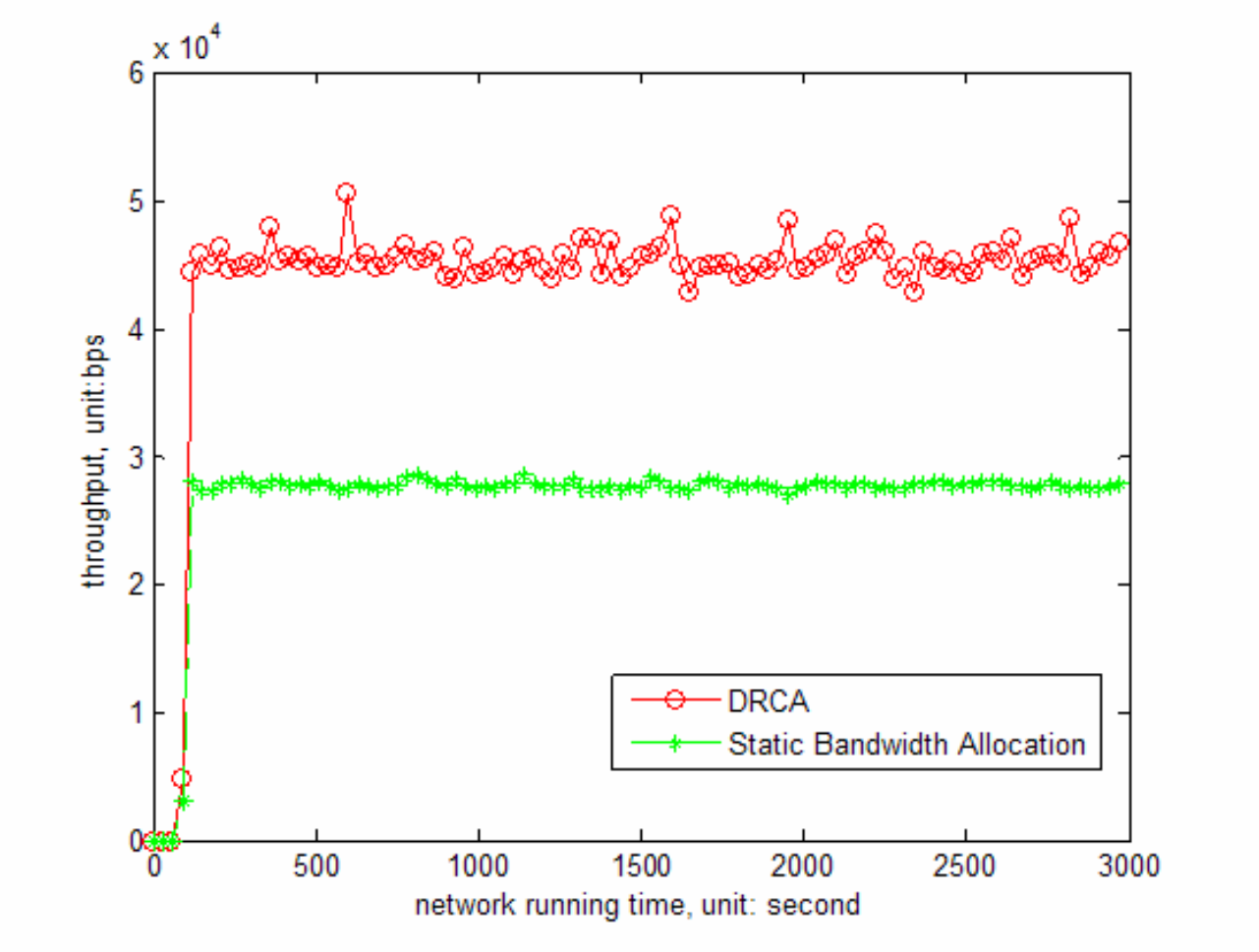
21 pairs of active mobile terminals



16 pairs of active mobile terminals



12 pairs of active mobile terminals



Throughput Difference

Number of active MT pairs	Average Throughput Difference
25	9.48%
21	21.09%
16	40.57%
12	63.32%

Conclusions

- DRCA achieves much higher throughput than static spread code allocation methods;
- The difference increases with the number of inactive mobile terminals in the network

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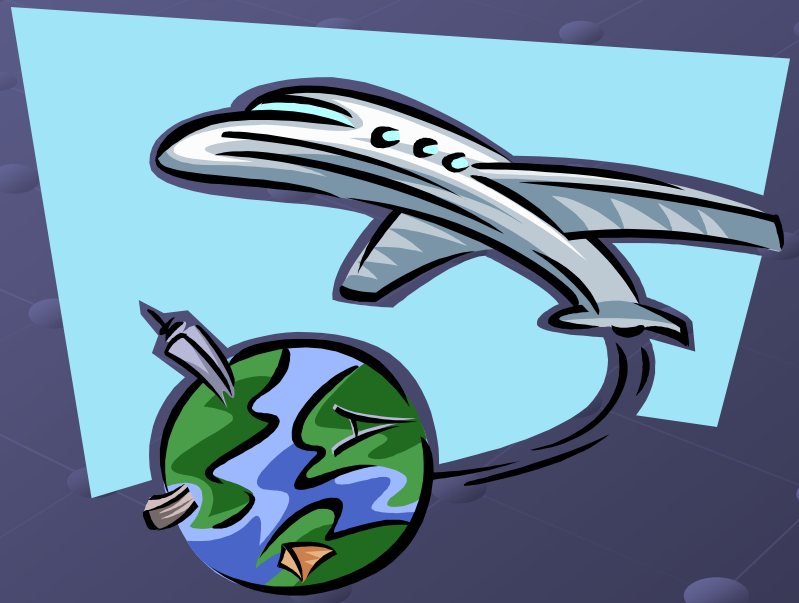
Thank You !

Questions?