Routing in a Delay Tolerant Network

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Presented by Xun Gong

Outline

- Delay Tolerant Networks
- Routing Problem in DTNs
- Multiple-copy Approach
  - Flooding and Variants
- Single-copy Approach
  - Routing in a Delay Tolerant Network
  - Efficient Routing in Intermittently Connected Mobile Networks: The Single-Copy Case

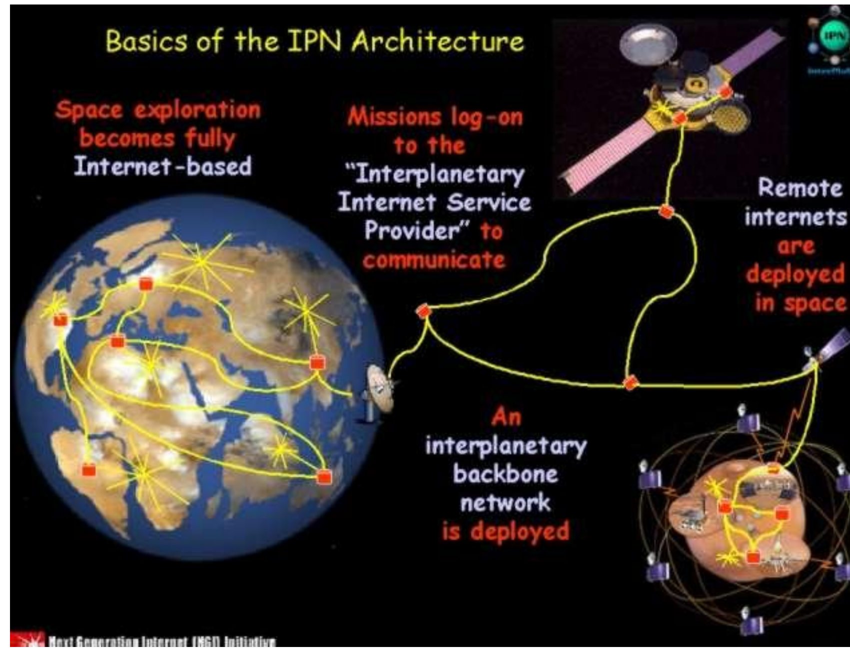
Delay Tolerant Network

- DTNs = Delay/Disruption/Disconnection Tolerant Networks
  - Challenged networks
  - Lack of end-to-end paths due to network partitions
  - Can tolerate delay/disruption/disconnection
- ITRF-DTNRG (DTN Research Group)[1]
  - Architecture and protocol design
  - Related resources

1. http://www.dtnrg.org/wiki

Interplanetary Internet

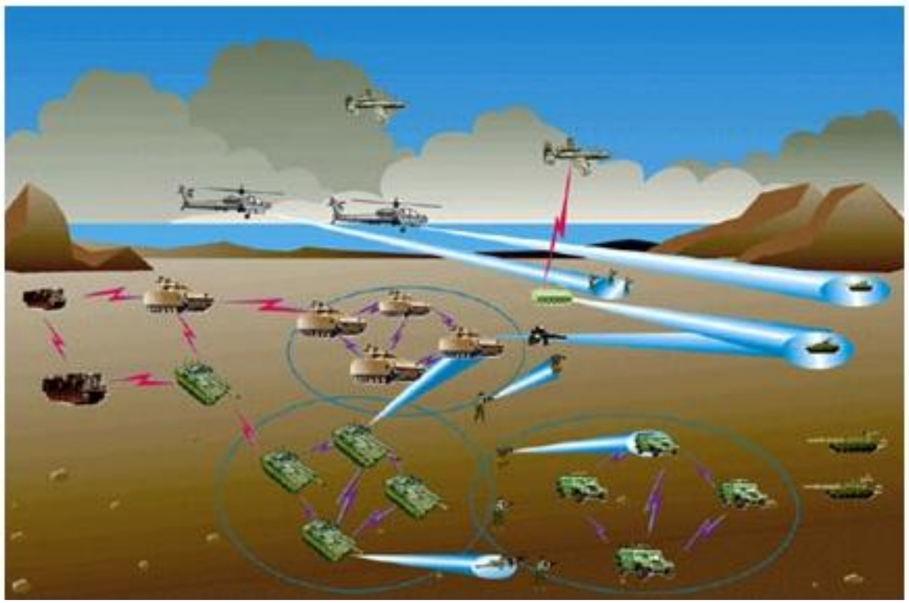
- Inter-Planet Satellite Communication Network (Vint Cerf et al)[1]
  - Extremely long propagations due to the limitation of speed of light
  - Dynamic connectivity
  - Low transmission reliability



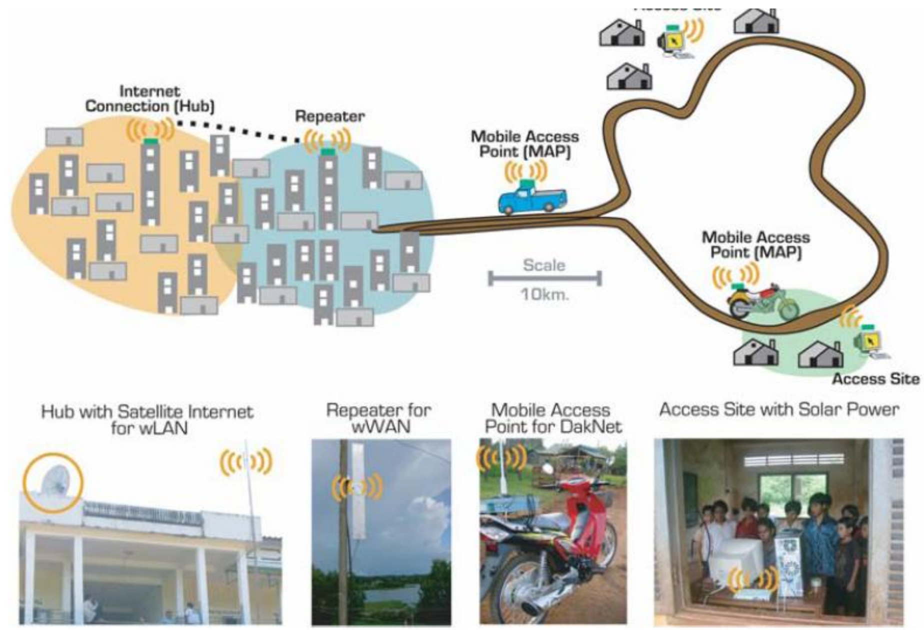
1. http://ipnsig.org/home.htm

Other Challenged Networks

Military Battlefield Network[1]



Village Network[2]



1. http://www.darpa.mil/sto/solicitations/DTN/
2. http://www.firstmilesolutions.com/

Properties of DTN

- Comparison with conventional networks

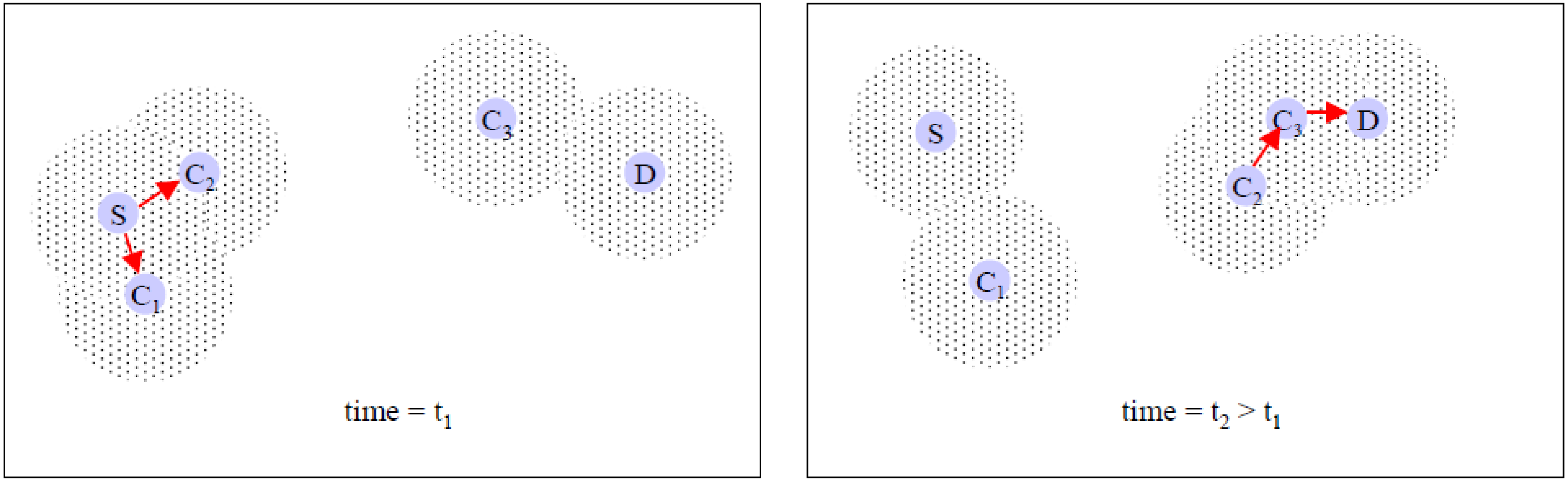
	Conventional Network	DTN
Connectivity	Continuous	Frequent disconnections
Propagation Delay	Short	Long
Transmission Reliability	High	Low
Link Rate	Symmetric	Asymmetric

Routing Problem in DTN

- Conventional Networks
  - End-to end path exists
  - Find the “best” path to send the data
- DTN
  - No contemporaneous end-to-end path
  - Store-and-Forward
  - Maximize the delivery probability constrained on finite buffers
  - Minimize the delay of a message
- Multiple-copy and Single-copy approaches

Multiple-copy Approach

- Flooding/Epidemic routing [A. Vahdat, 2000]
  - Nodes replicate and transmit message to newly discovered contacts



  - Easy to implement
  - Resource consuming

Flooding variants

- Spray and Wait [T. Spyropoulos, 2005]
  - Spray phase: send copies to at most L contacted neighbors
  - Wait phase: hope one contacted neighbor meets the destination
- PRoPHET [A. Lindgren, 2003]
  - Send copies to neighbors with high probability of delivery based on history

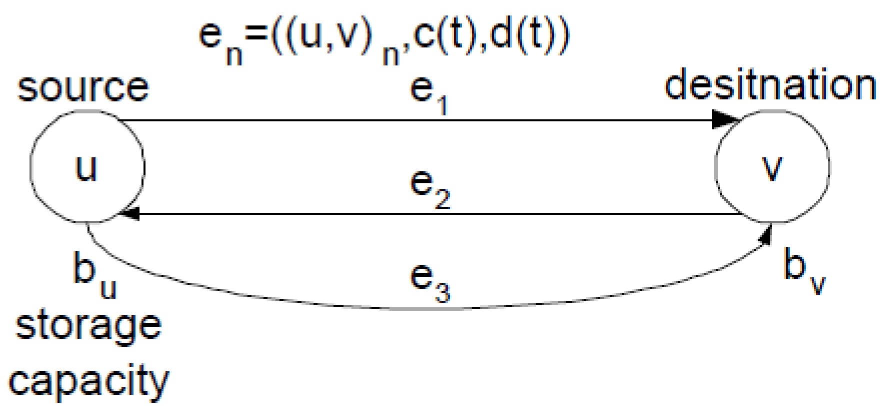
Routing in a Delay Tolerant Network

Authors: Sushant Jain, Kevin Fall and Rabin Patra, SIGCOMM 2004

- Multiple-copy routing
  - Resource consuming
  - Heuristic, Optimal?
- Single-copy routing
  - No replicas of messages
  - Time-varying connectivity graph
  - Minimize the delay of a message

Directed Multi-graph Model

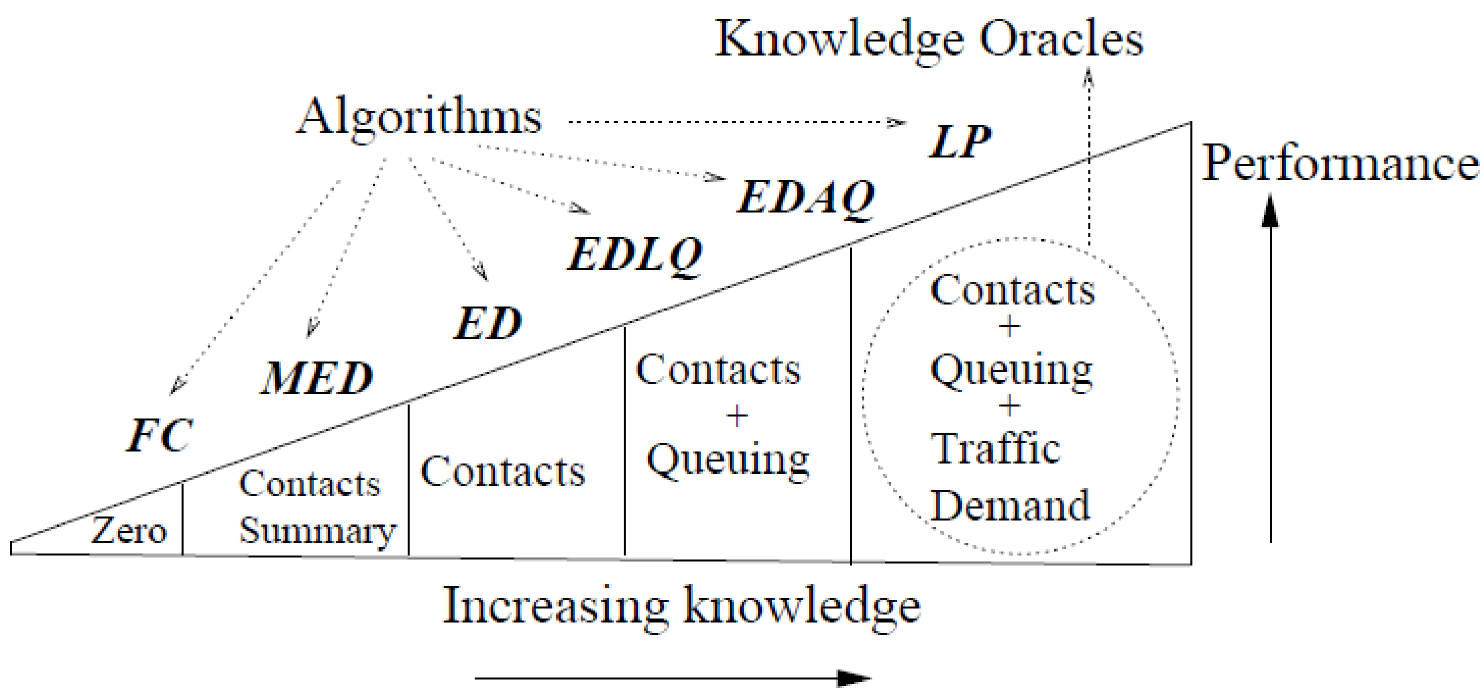
- Nodes: storage capacity *b*
- Edges: (u, v), c(t), d(t)
- Messages: (u, v, t, m)
- Contacts: an edge has positive c(t)



Knowledge Oracles

- Edge information: Contact summary:
  - Average waiting time until the next contact
- Edge information: Contacts:
  - Capacity and propagation delay of contacts at any time
- Node information: Queuing:
  - Buffer occupancies at any node at any time
- Traffic demand:
  - Messages injected into the system at present or future

Routing Algorithms



Routing with Zero Knowledge

- Algorithm: First Contact (FC)
  - Randomly choose an edge among all current contacts and forward the message
- Trivial to implement
- Poor performance
  - No progress towards the destination
- Not loop free
  - Use path vector style methods

Routing with Complete Knowledge

- Knowledge: contacts, queuing + traffic demands
- Algorithm: Linear Programming (LP)
  - A set of disjoint time intervals
  - Predict the delays of all messages
  - Minimize the average delay under constraints of buffers and capacities
- Optimal solution
- Impractical in general
- Hard to scale

Routing with Partial Knowledge

- Contact summary/Contacts/Queuing
- "Shortest" path problem
  - Assign delay cost to edges

$$w(e,t,m,s) = t'(e,t,m,s) - t + d(e,t')$$

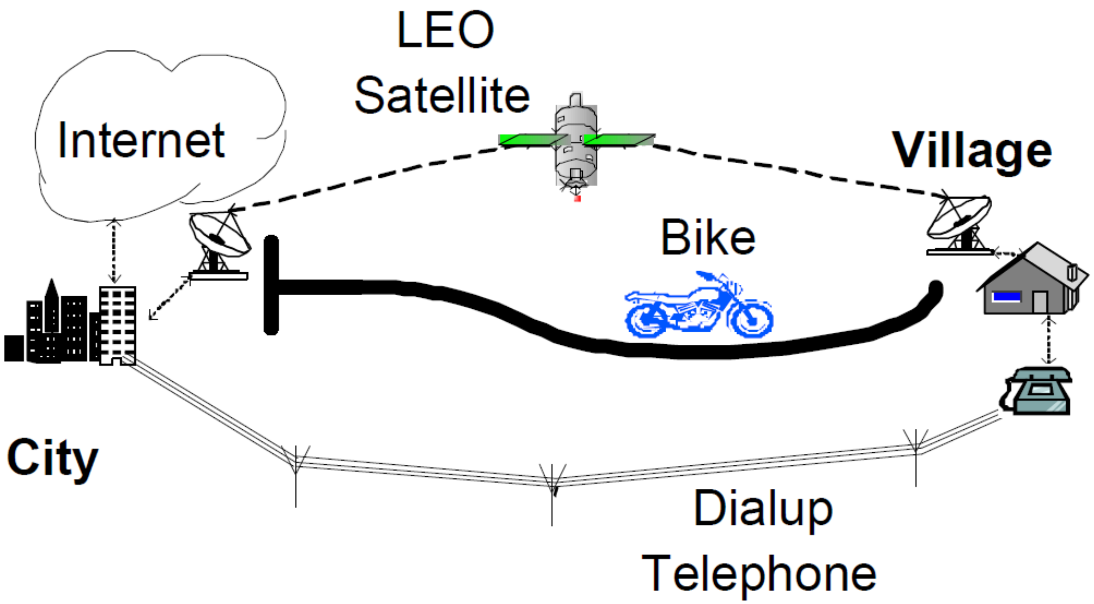
$$t'(e,t,m,s) = \min\{t'' \mid \int_{x=t}^{t''} c(e,x)dx \geq (m + Q(e,t,s))\}$$

  - Dijkstra's shortest path algorithm
- Sub-optimal solution

Routing with Partial Knowledge

- Knowledge: contact summary
  - Minimum Expected Delay (MED)
  - Time-Invariant and offline
- Knowledge: contacts
  - Earliest Delivery (ED) and Earliest Delivery with Local Queuing (EDLQ)
- Knowledge: contacts + queuing
  - Earliest Delivery with All Queues (EDAQ)

Simulation



Dialup

- 4 Kbps
- 11 pm to 6 am

Satellite

- 10 Kbps
- 4 services per day
- Each10 minutes

Bike

- 1 Mbps
- 128MB
- 5 Minutes
- 2 hours one way

Performance Results

- Message 1KB and 10 KB

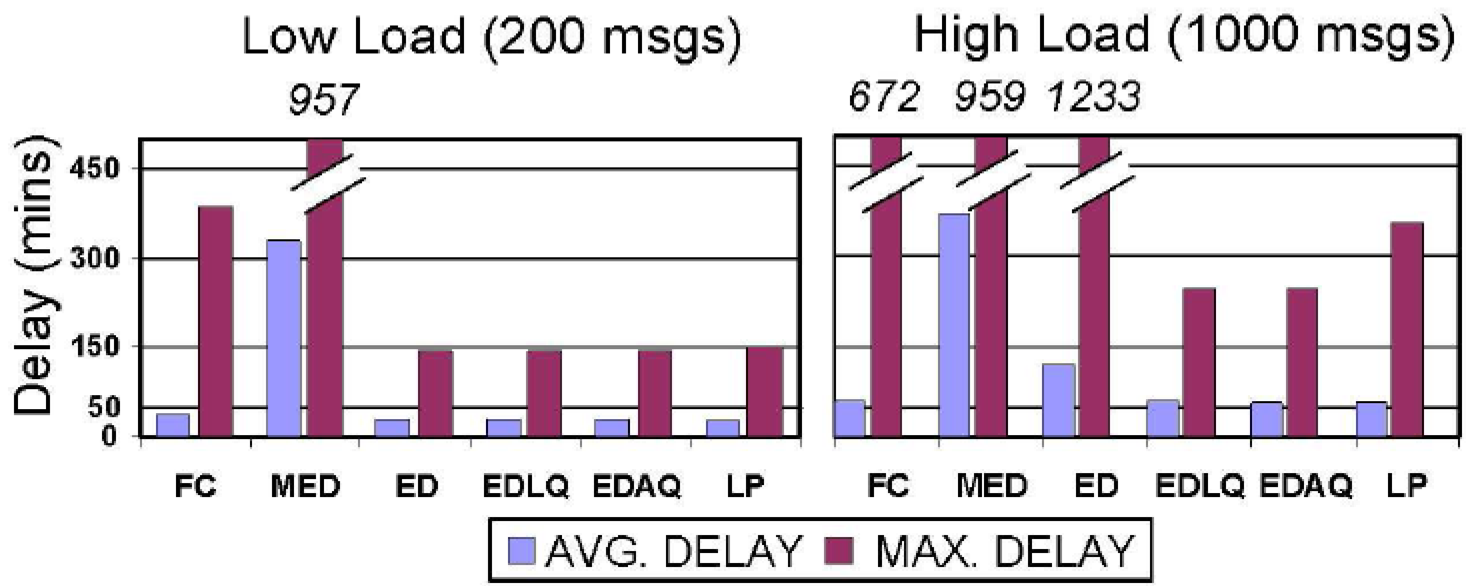


Figure 5: Delay comparison for different algorithms.

Limitations

- Oracle Knowledge
  - Dynamics of graphs, traffic demands
- Cannot applied to opportunistic connectivity
  - Mobile networks
- Efficient Routing [T. Spyropoulos]
  - Timer
  - Historical Knowledge

References

A. Vahdat and D. Becker. **Epidemic Routing for Partially Connected Ad Hoc Networks.** Duke University technical report , July 2000.

T. Spyropoulos, K. Psounis and C. S. Raghavendra**. Spray and Wait: An Efficient Routing Scheme for Intermittently Connected Mobile Networks.** SIGCOMM 2005.

A. Lindgren, A. Doria, and O. Scheln. **Probabilistic routing in intermittent ly connected networks.** MobiHoc 2003.

T. Spyropoulos, K. Psounis and C. S. Raghavendra**. Efficient Routing in Intermittently Connected Mobile Networks: The Single-Copy Case.** IEEE Transaction on Networking, Vol 16. No., February 2008.

Thanks!

Summary of Algorithms

Abbr.	Name	Description	Oracles Used
FC	First Contact	Use any available contact	None
MED	Minimum Expected Delay	Dijkstra with time-invariant edge costs based on average edge waiting time	Contacts Summary
ED	Earliest Delivery	Modified Dijkstra with time-varying cost function based on waiting time	Contacts
EDLQ	Earliest Delivery with Local Queue	ED with cost function incorporating local queuing	Contacts
EDAQ	Earliest Delivery with All Queue	ED with cost function incorporating queuing information at all nodes and using reservations	Contacts and Queuing
LP	Linear Program	-	Contacts, Queuing and Traffic

Routing with Complete Knowledge

- Knowledge: contacts, queuing and traffic demands
- Linear Programming Formulation
  - Time intervals: $I_1, \dots I_q, \dots, I_h \in ב_E, I_q = [t_{q-1}, t_q)$
  - K, the message set. $(s(k), d(k), \omega(k), m(k)), k \in K$
  - $X_{e,I}^k$, the amount of message k transmitted over e during I
  - $R_{e,I}^k$, the amount of message k received over e during I
  - I^v, the set of edges whose destination node is v
  - O^v, the set of edges whose source node is v
  - K^v, the set of messages whose destination node is v
  - $\min \sum_{v \in V} \sum_{k \in K^v} \sum_{I_q \in ב_E} (t_{q-1} - \omega(k)) \cdot \left(\sum_{e \in \mathrm{I}^v} R_{e,I_q}^k - \sum_{e \in \mathrm{O}^v} X_{e,I_q}^k\right)$