Discussion of “Bits-per-Joule Capacity of Wireless Ad Hoc Networks”

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Outline

- Ad Hoc Nets Special Challenges
- Network Model
- Traffic and Node Energy Model
- Capacity of a given topology
- Simulation Results

Special Challenges of Ad Hoc Nets

- No infrastructure
- Decentralized control (power, routing, data rates, etc)
- Dynamic topology
- Wireless channel impairments

Bits per Joule capacity : why?

- In the wirelessLAN domain, BW is plentiful. Ex:
  - 5GHz carrier$\longrightarrow$TotalBW=300MHz ; 13 chans
  - 60GHz carrier$\longrightarrow$TotalBW=5GHz; 100’s chans
- More BW than applications can consume. Bps capacity no longer relevant
- BpJ-capacity : Max # of bits a network can deliver per Joule of energy in the network
- It can be shown that adhoc networks have a much greater bpJ capacity than cellular nets

Network Model-1

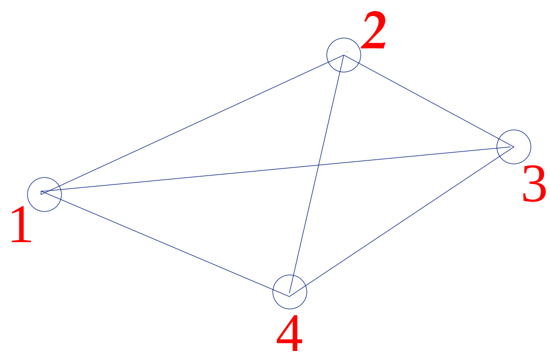
- Set of stationary nodes $\mathcal{N}$ over a deployment region
- Each node i :
  - has enough power to reach any other node
  - can transmit at minimal power needed to reach destination
  - can use multihop
  - has finite energy E_i
  - receives/processes at NO energy cost

Network Model–2

- c_{ij} : cost in Joules-per-bit of link ij
- $d^{(m,n)}$: amount of traffic m wishes to send to n
- $x_{ij}^{(m,n)}$: flow of traffic (m,n) on link ij
- Γ : matrix s.t. $\Gamma_{mn} = 1$ if $d^{(m,n)} > 0$, $\Gamma_{mn} = 0$ o/w
  Ex: 4 nodes, only $d^{(1,3)}$ and $d^{(4,3)}$ are > 0

$$\begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

Network Model –3



Demands are feasible if constraints below can be satisfied

- $\sum_{j \in \mathcal{N} \setminus \{i\}} x_{ji}^{(m,i)} = d^{(m,i)}$ e.g., $\rightarrow$

$$x_{1,3}^{(1,3)} + x_{2,3}^{(1,3)} + x_{4,3}^{(1,3)} = d^{(1,3)}$$

- for $p \neq i$ $l \neq i$, $\sum_{j \in \mathcal{N} \setminus \{i\}} x_{ji}^{(l,p)} = \sum_{k \in \mathcal{N} \setminus \{i\}} x_{ik}^{(l,p)}$

$$x_{14}^{(1,3)} + x_{24}^{(1,3)} = x_{41}^{(1,3)} + x_{42}^{(1,3)} + x_{43}^{(1,3)}$$

- $\sum_{m \in \mathcal{N}} \sum_{n \in \mathcal{N}} \sum_{k \in \mathcal{N}} c_{ik} x_{ik}^{(m,n)} \leq E_i$

$$c_{41} x_{41}^{(1,3)} + c_{42} x_{42}^{(1,3)} + c_{43} x_{43}^{(1,3)} +$$
$$c_{41} x_{41}^{(4,3)} + c_{42} x_{42}^{(4,3)} + c_{43} x_{43}^{(4,3)} \leq E_4$$

Traffic Models

1. One-to-one: each node generates demand for exactly one randomly chosen node.
   objective funct.: $\max \sum \sum d^{(m,n)} \longleftarrow$ ("sum capacity")
2. Many-to-one: all demands are like $d^{(m,1)}$
   obj. func.: max min $d^{(m,1)} \longleftarrow$ ("maxmin capacity")
3. One-to-many: all demands are like $d^{(1,n)}$
   obj. func.: min max $d^{(1,n)} \longleftarrow$ ("minmax capacity")

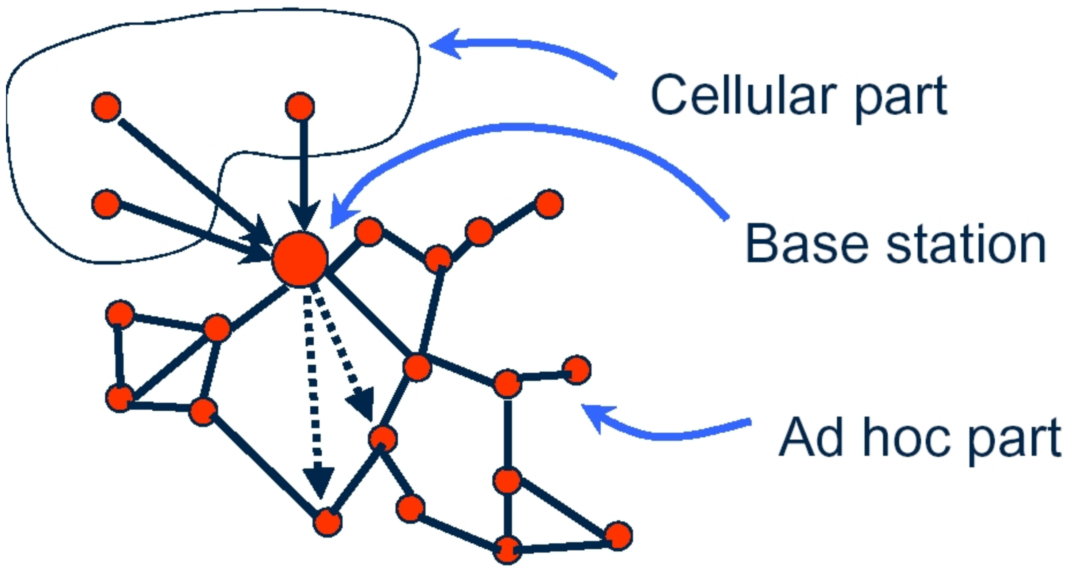
- bpJ-capacity : divide above capacity by $\sum E_i$
- Assume node energies are of same order of magnitude

Capacity of a Topology

- A "fully-connected graph" has been assumed. If not true :
  - Pretend the network is fully-connected
  - Add the additional constraint $x_{ij}^{(m,n)} = 0$ for any link ij that is not part of the actual network (or $c_{ij} = \infty$)
- Some topologies
  1. Minimum energy graph (1999 paper)
  2. K-best-neighbor graph (each node only transmit thru the best K (lowest energy/bit) channels)
  3. "ad hoc cellular hybrid" (1 BS operates at NO energy cost; in many-1 and 1-many traffic, BS is "1")

Adhoc-cellular Hybrid

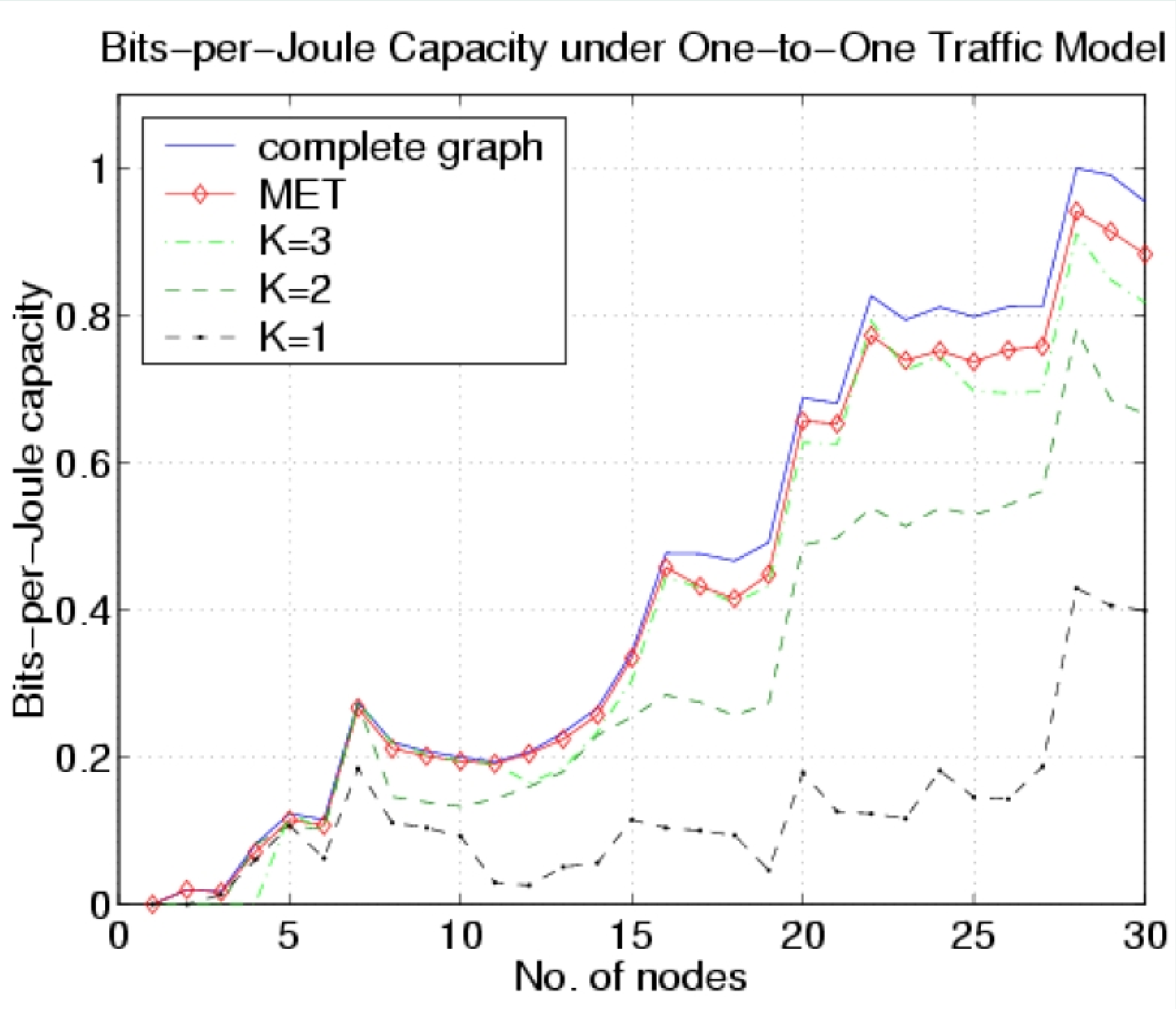
Nodes in the cellular part see “uplinks” or “downlinks” to BS. To adhoc nodes, BS is just another node. In 1-to-1 traffic, BS relays traffic at NO energy cost. In many-to-1, BS is info “sink”. In 1-to-many, BS is the info “source”; its energy is constrained.



Simulation Setup

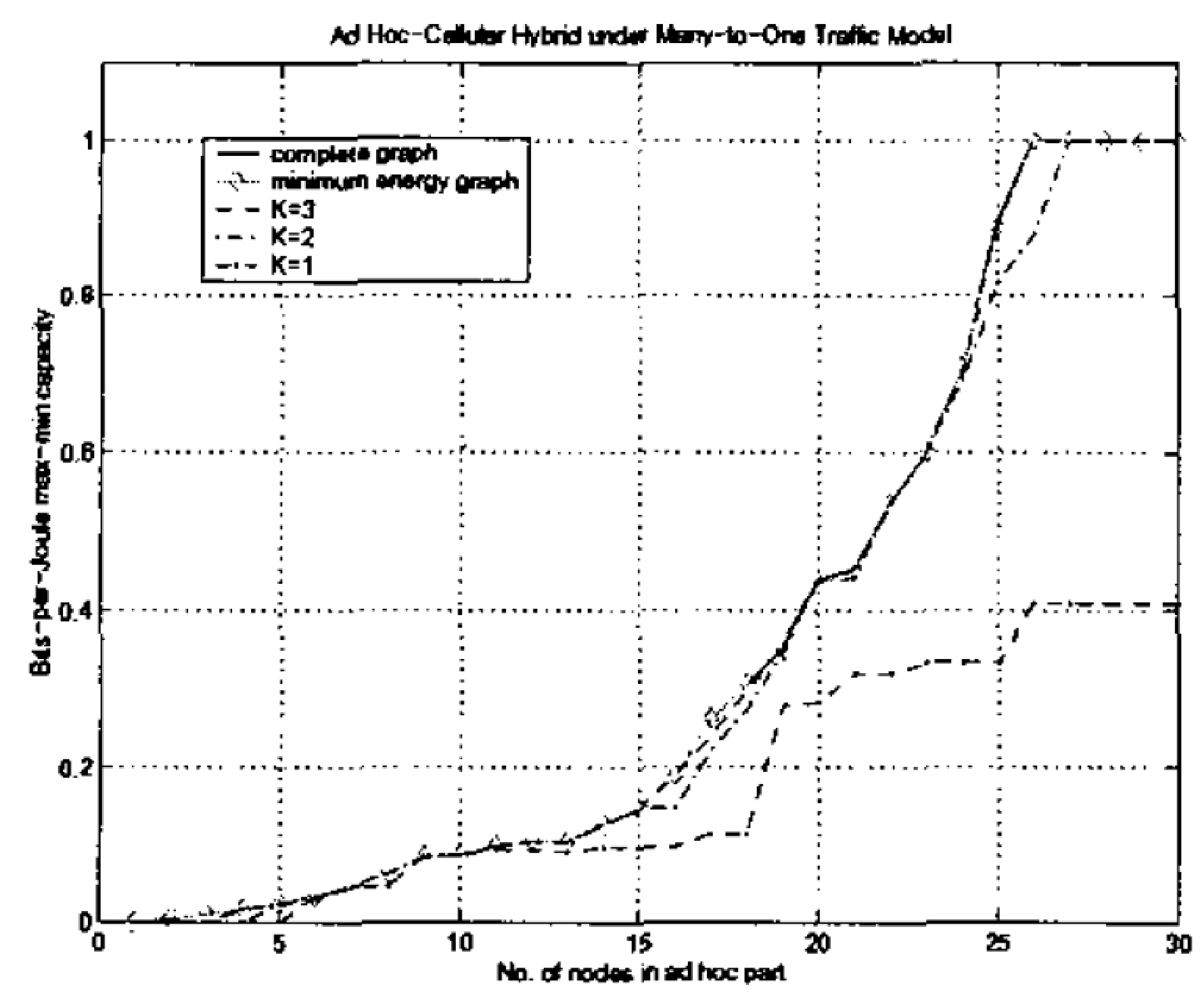
- Deployment area : 120m $\times$120m square
- Propagation : urban, outdoor

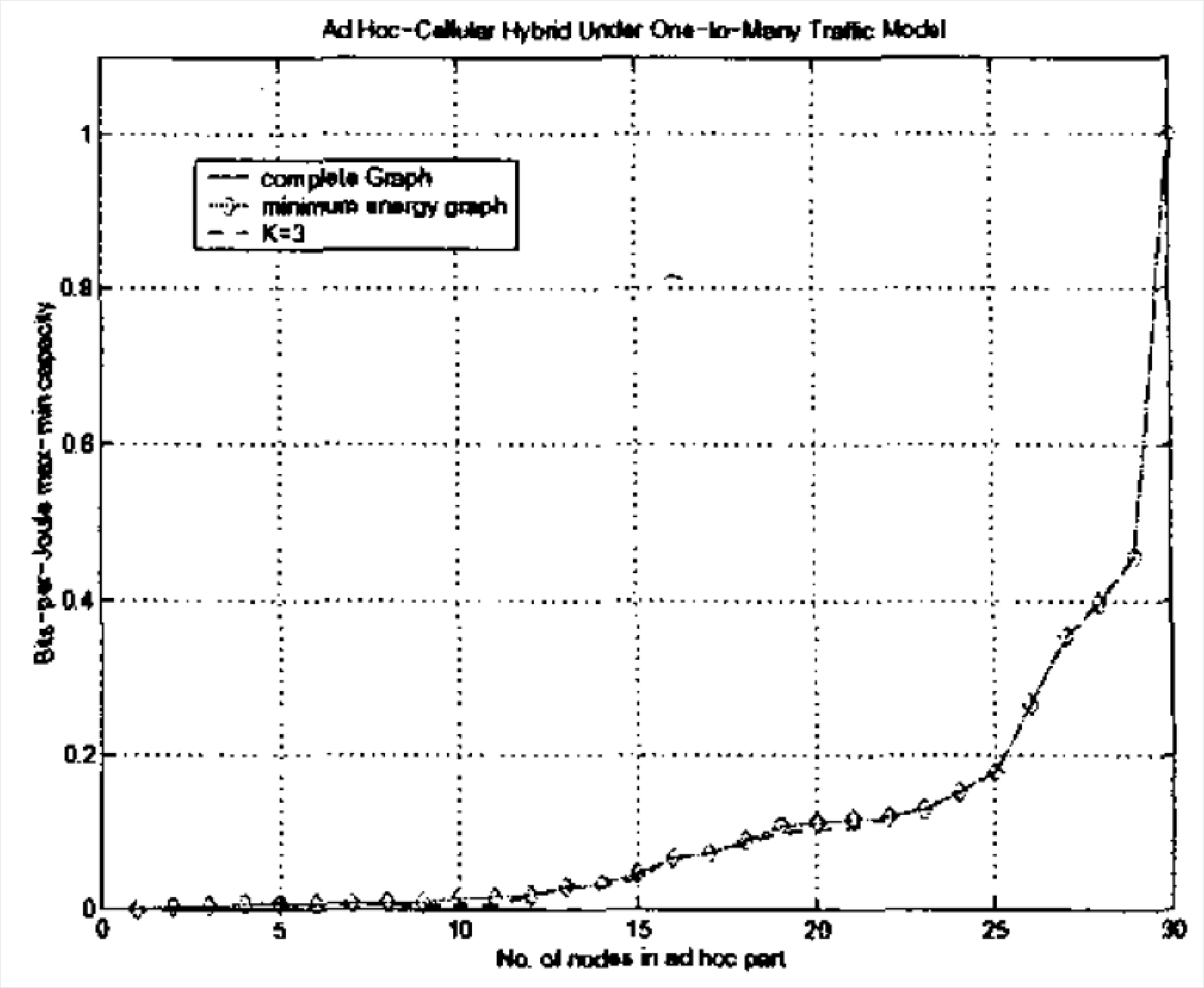
  (models by Feuerstein, et al., ’94 and Gudmunson, ’91)
- Node locations: ind. , uniform
- Energies: ind., uniform in [0.2, 1] J



Bits–per–Joule Capacity under One–to–One Traffic Model
complete graph
MET
K=3
K=2
K=1
Bits–per–Joule capacity
No. of nodes
0
0.2
0.4
0.6
0.8
1
0
5
10
15
20
25
30

Ad Hoc–Cellular Hybrid under One–to–One Traffic Model
C = 0 (complete)
C = 0 (MET)
C = 0 (K=3)
C = 5 (complete)
C = 5 (MET)
C = 5 (K=3)
C = 10 (complete)
C = 10 (MET)
C = 10 (K=3)
Bits–per–Joule capacity
No. of nodes
0
0.2
0.4
0.6
0.8
1
0
5
10
15
20
25
30


Ad Hoc-Cellular Hybrid under Many-to-One Traffic Model
complete graph
minimum energy graph
K=3
K=2
K=1
Bits-per-Joule max-min capacity
No. of nodes in ad hoc part
0
0.2
0.4
0.6
0.8
1
0
5
10
15
20
25
30



Ad Hoc-Cellular Hybrid Under One-to-Many Traffic Model
complete Graph
minimum energy graph
K=3
Bits-per-Joule max-min capacity
No. of nodes in ad hoc part
0
0.2
0.4
0.6
0.8
1
0
5
10
15
20
25
30

Discussion

- MET and 3-BNT can achieve most of the capacity of the fully-connected graph, although they are “sparce”.
- Pathologies are possible, even if $E_i \approx E_j \; \forall i, j$:
  - for MET, bpJ$\downarrow$ 0 as n$\longrightarrow \infty$
  - bpJ=0 for K-BNT with K<N/2 and 1-1 traffic, for some demands
- NO such pathologies for randomly deployed nodes
- With 1-1 traffic, adhoc arch. dominates cellular, beyond a certain # of nodes (18). Under other traffic patterns, adhoc arch. also performs better.