UWB Network Organization

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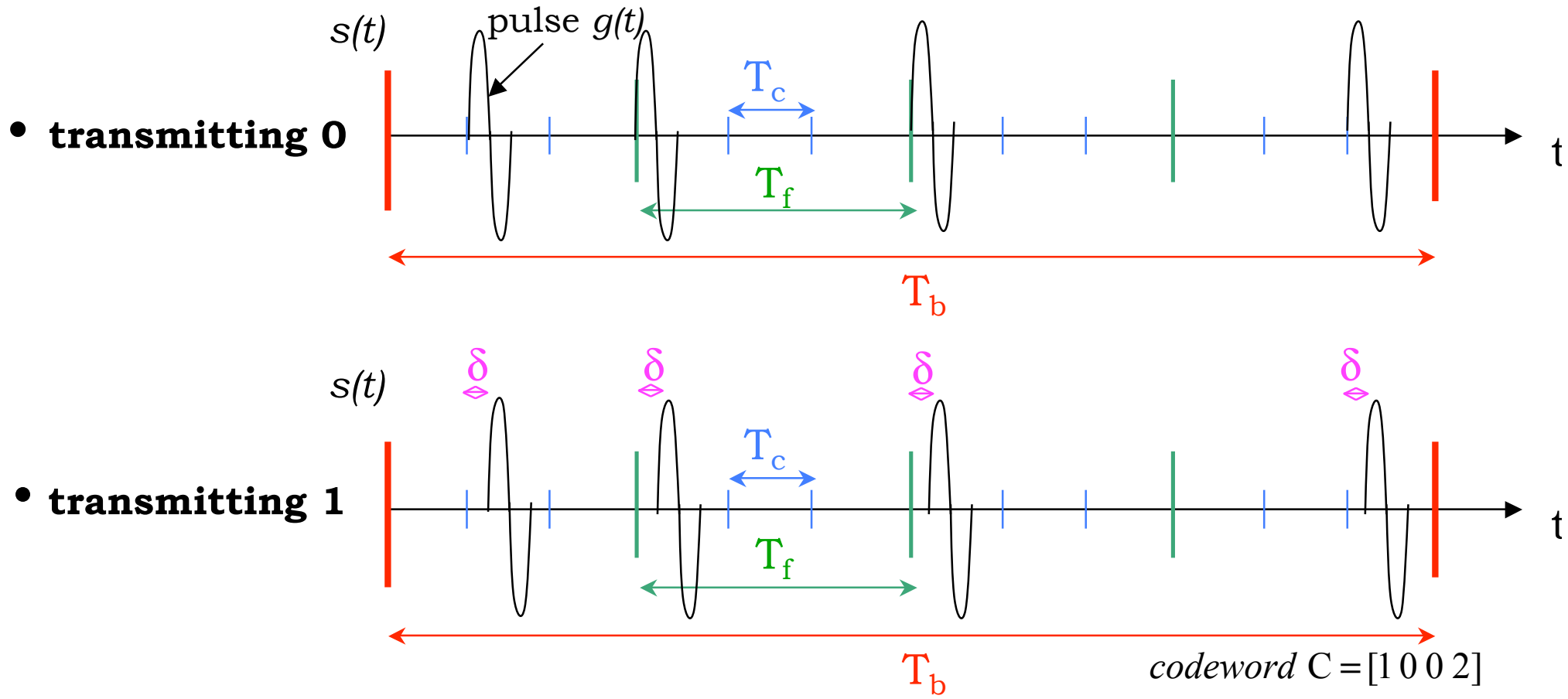
UWB is …

- UltraWideBand
- Impulse radio
- Carrier-free
- Baseband
- Time domain
- Nonsinusoidal
- ...

UWB characteristics

- ultra short duration pulses ⟶ ultra wideband signals
- very low power spectral density
- high fractional bandwidth $\eta = 2\frac{f_H - f_L}{f_H + f_L} > 25\%$
- excellent immunity to interference from other radio systems
- coexistence with other systems
- PPM / PAM modulation
- multiple access spread spectrum

UWB transmitted signal



$$s(t) = \sum_{i=-\infty}^{+\infty} \sum_{j=0}^{Ns-1} g\left(t - iT_b - jT_f - c_j T_c - b_i \delta\right)$$

codeword C = [1 0 0 2]

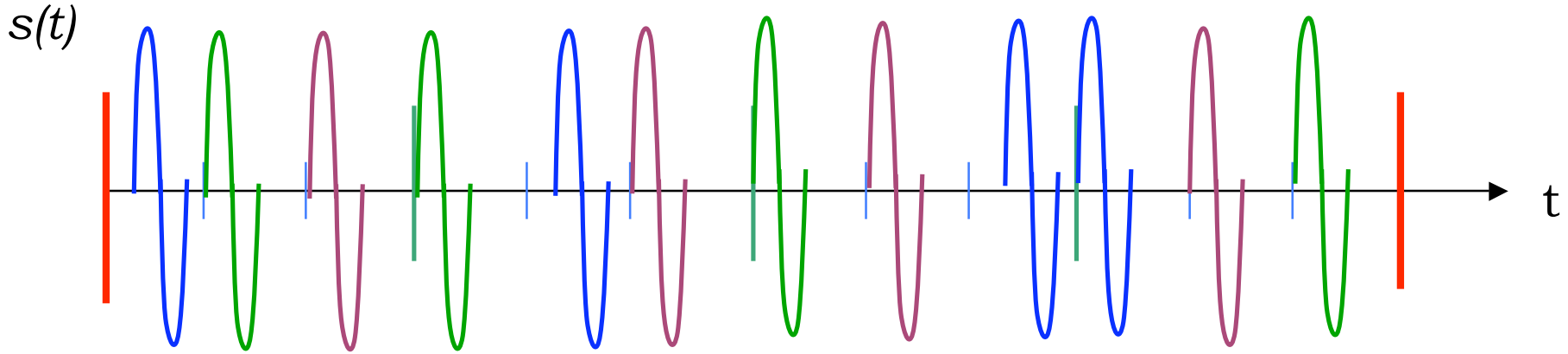
code period $N_p = 4$

$T_b = N_s \cdot T_f$ *i.e.* $T_b = 4 \cdot T_f$

$T_f \geq N_h \cdot T_c$ *i.e.* $T_f = 3 \cdot T_c$

$N_s = N_p$

UWB multiple access



$C^{(1)}=[1\ 0\ 0\ 2]$ $b_1=0$

$C^{(2)}=[0\ 1\ 2\ 0]$ $b_2=1$

$C^{(3)}=[2\ 2\ 1\ 0]$ $b_3=0$

- When the number of users is U, the transmitted signal is:

$$s(t)=\sum_{k=1}^{U}\sum_{i=-\infty}^{+\infty}\sum_{j=0}^{Ns-1} g\left(t-iT_b-jT_f-c_j^{(k)}T_c-b_i^{(k)}\delta\right)$$

UWB and wireless networking

- What UWB offers to wireless networking:
  - Precise ranging (localization with distributed processing)
  - High robustness for indoor applications
  - Low power requirements
- What UWB requires:
  - Fine power tuning in order to meet power limits
  - Efficient synchronization algorithms to reduce link set-up time and synchronization overhead

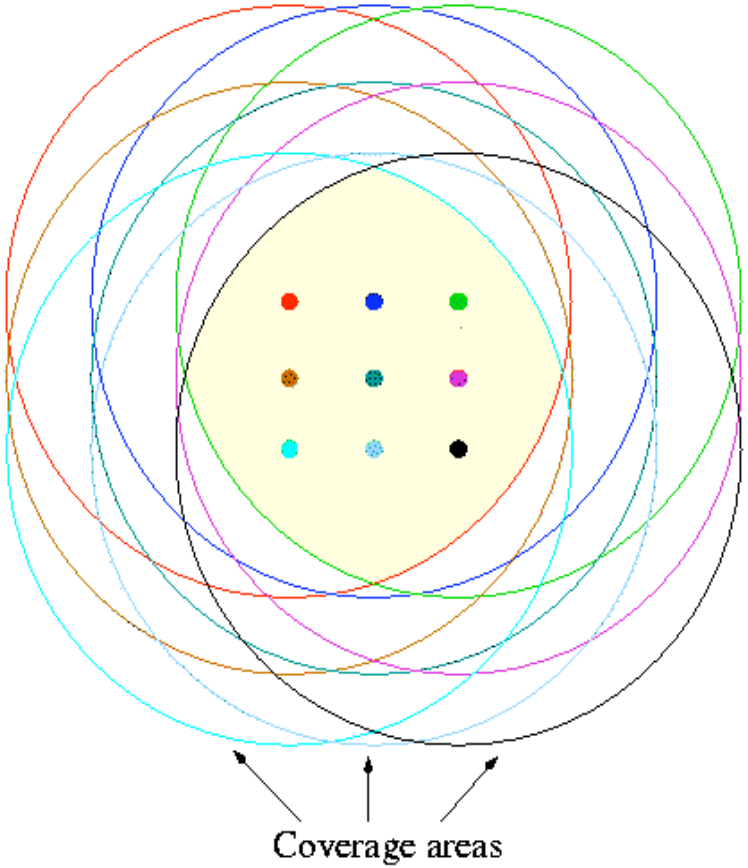
Optimal solution for UWB networks:

power-efficient, location-based routing strategy

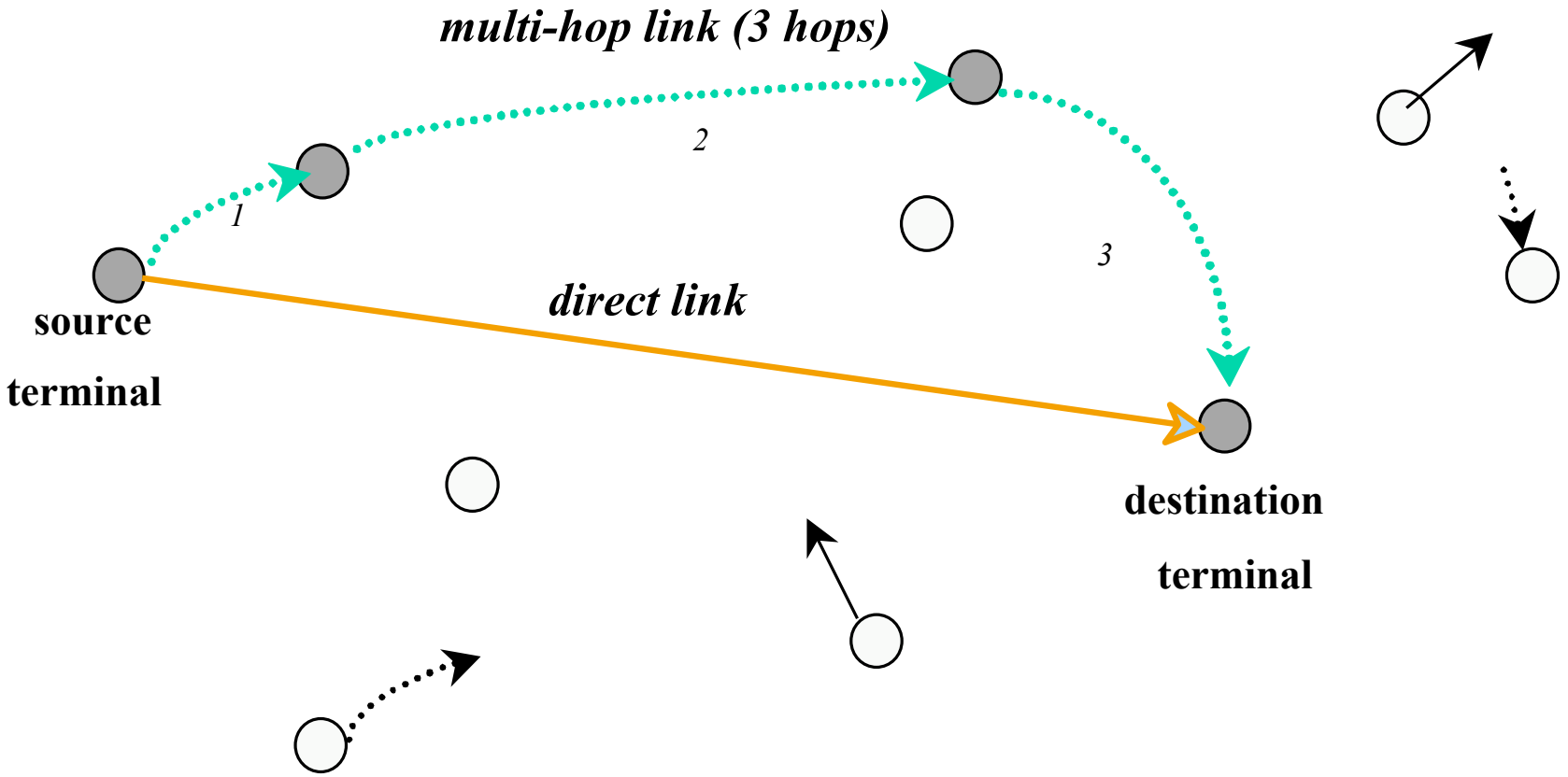
Reference model

MODEL of the Universe

Coverage area: all nodes are within reach of each other

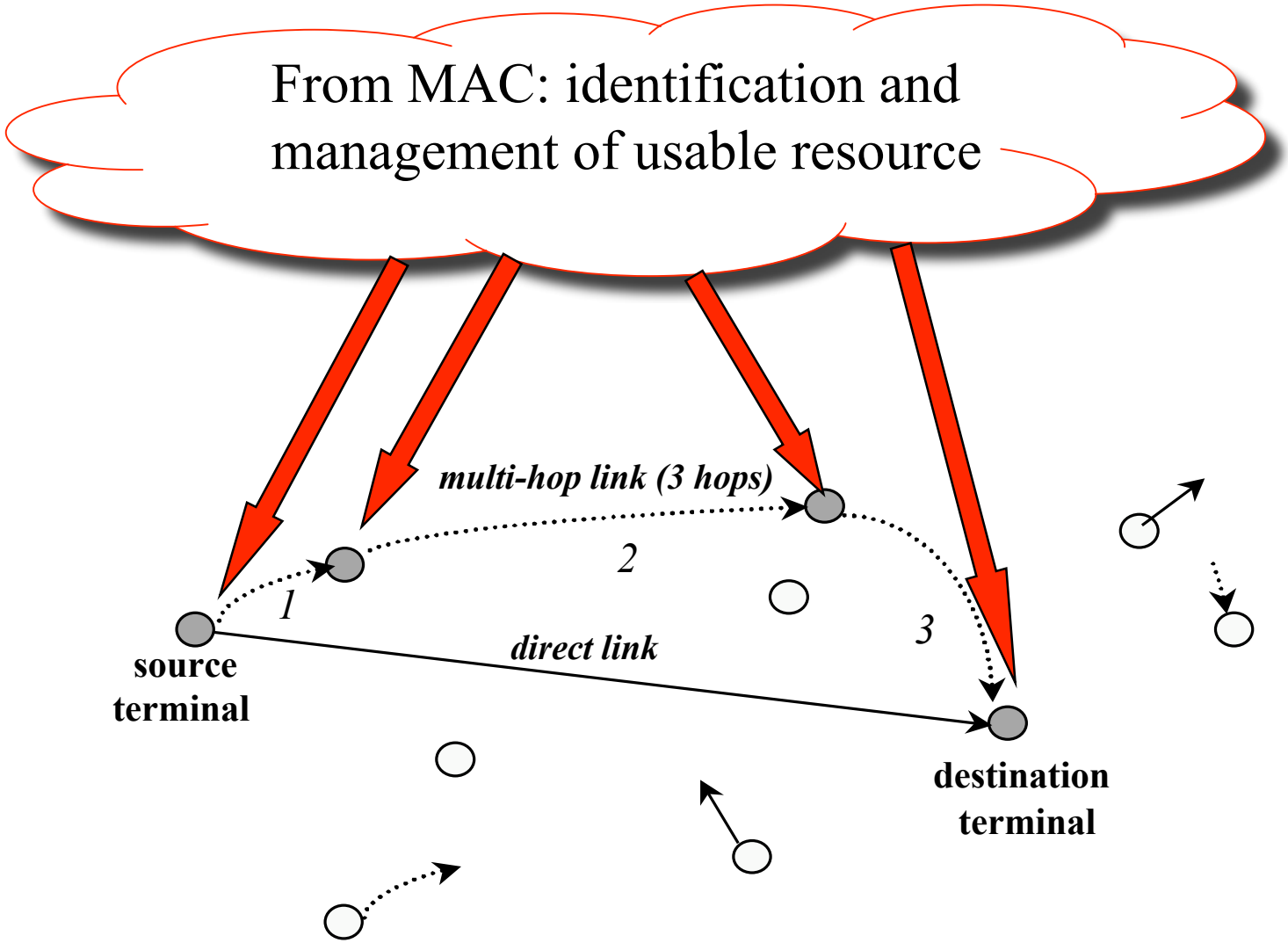


Reference model

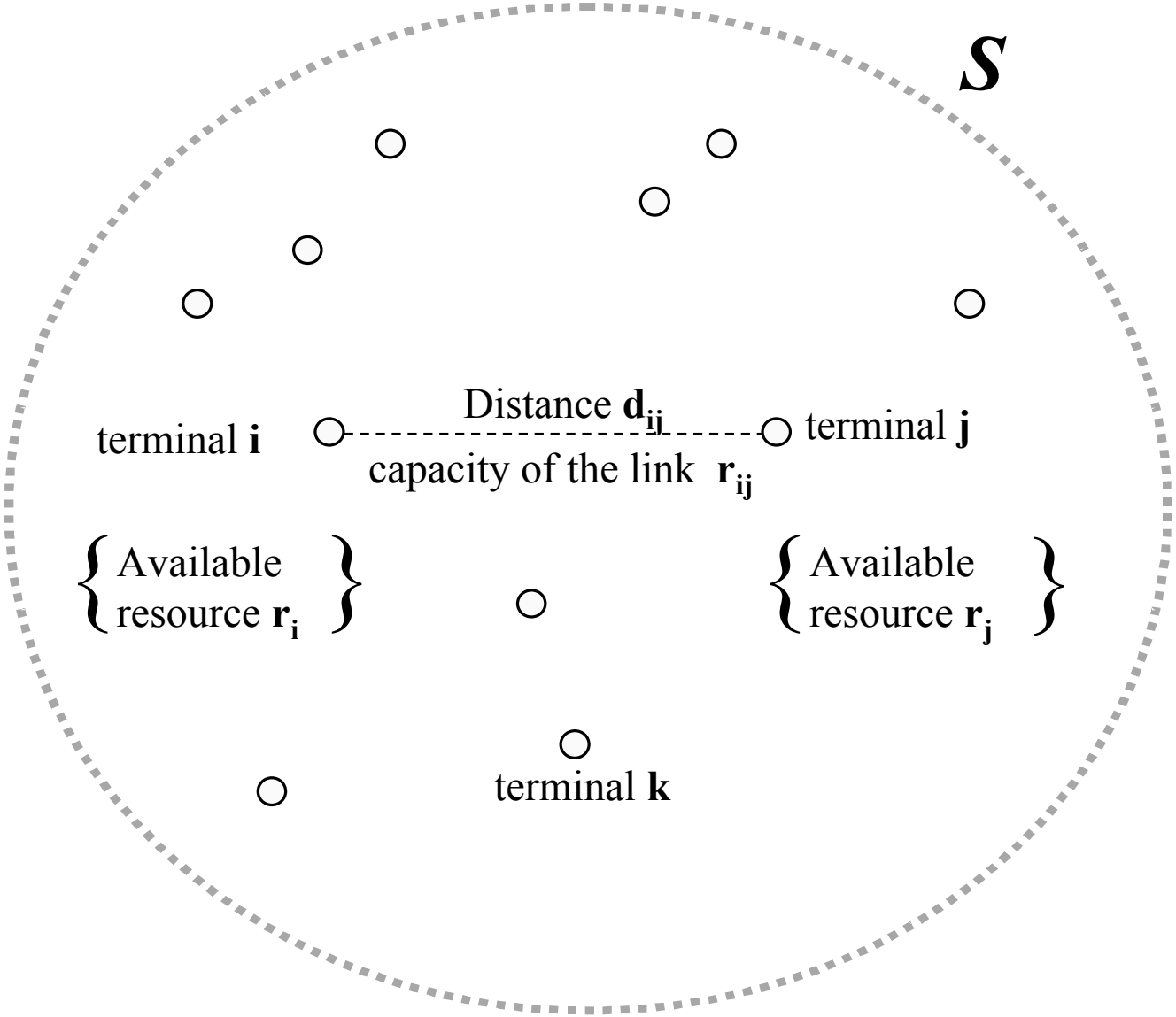


Connection between a source terminal and a destination terminal through a direct path i.e. one hop link, and a multi-hop link made of 3 hops

Reference model



Reference model



Cost function

- Most often, cost functions correspond to number of hops:

  Cost of single link: ∞ (no visibility); 1 (visibility).

If visibility is granted, there is no multi-hop.

- In our model we introduce a power-related cost function for each link:

$$C_{ij}(t) = \begin{cases} \infty & \text{if } r_{ij}(t) < R_{ij}(t) \\ C_0 \cdot d_{ij}^{\alpha} \cdot a_{ij}(t) + C_1 \cdot d_{ij}^{\alpha} \cdot R_{ij}(t) & \text{if } r_{ij}(t) \geq R_{ij}(t) \end{cases}$$

Requested resource

Set-up cost term

Resource cost term

- We set a value for the maximum total cost (sum of all CF of active links) in the Network, called maximum NCF (Network Cost Function)

Path selection strategies

Traditional approaches:

- Absolute minimization of unitary cost function:

  → Metrics = Number of hops

- Absolute minimization of power-related cost function:

  → Metrics = Cost

New possibilities:

- Constrained minimization of number of hops :

  → Metrics = f (Number of hops, Cost)

- Constrained minimization of Network Cost Function:

  → Metrics = f (Cost, Number of hops)

Network topology

- Resulting network topology strictly depends on the adopted path selection strategy
- We expect network topology to resemble one of the three following models:
  - Regular network: each node is connected mainly with its short-distance neighbours
  - Random network: each node is connected with nodes positioned all over the network, at any distance
  - Small world network: intermediate between the two previous models - combines their properties

Small-World Networks

Properties

- Natural organization of a SW network:
  - topology with high clustering coefficient = high cliquishness
  - short average distance between two nodes = short path length

    i.e.:
    - many short-range connections
    - a few long-range connections (“shortcuts”).

Why Small-World?

Short path length

each node is efficiently connected to all possible destinations in the network

High cliquishness

Robustness to local link failure, thanks to high number of alternative local links

Path Length properties

- **Path Length is**
  - a property of the **graph** formed by the terminals and their physical links
  - strictly bound to the **maximum** distance between two nodes (**graph diameter**)

A network with a small diameter has normally a low path length and viceversa

- **Path Length is NOT:**
  - dependent upon the average number of **hops**

A strategy minimizing the number of hops may lead to a weakly connected graph, characterized by high Path Length

Algorithms for path selection strategies

- SingleHop algorithm
  - Set-up a connection only if a direct link is possible, i.e. if adding the cost of the direct link does not violate the maximum NCF
- MultiHop algorithm
  - Selects the path at lower cost considering **all** possible paths in the network
- Constrained-MultiHop algorithm
  - Selects the path at lower cost in a **subset** of all possible paths in the network
- Small-World algorithm
  - Set-up a direct link if possible, otherwise use a multi-hop path

Simulation Settings

- 25 Nodes on a Ring Lattice
- C_0=0.7, C_1=1, α=2

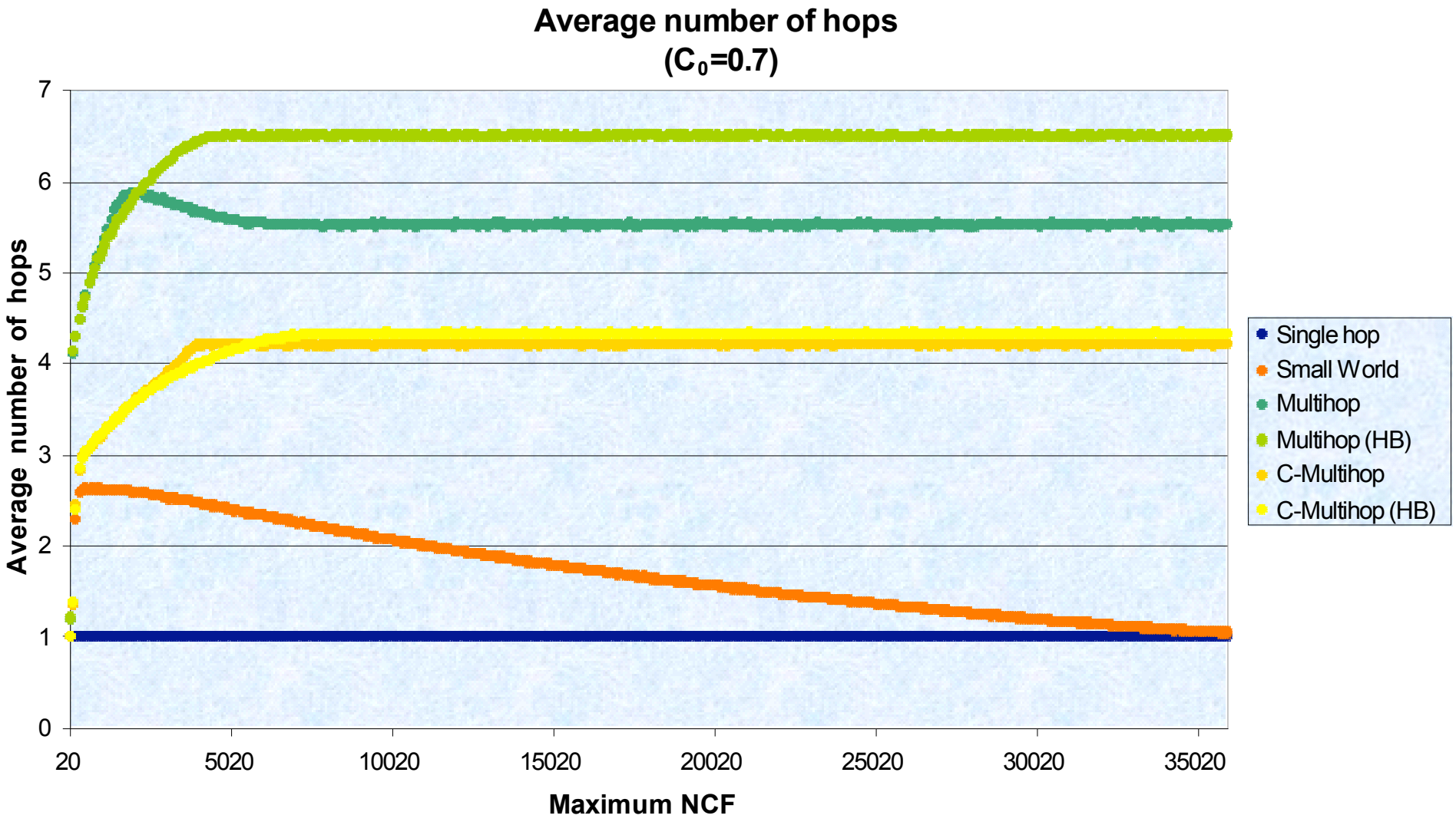
Single Hop and Small World algorithms:

- B=100

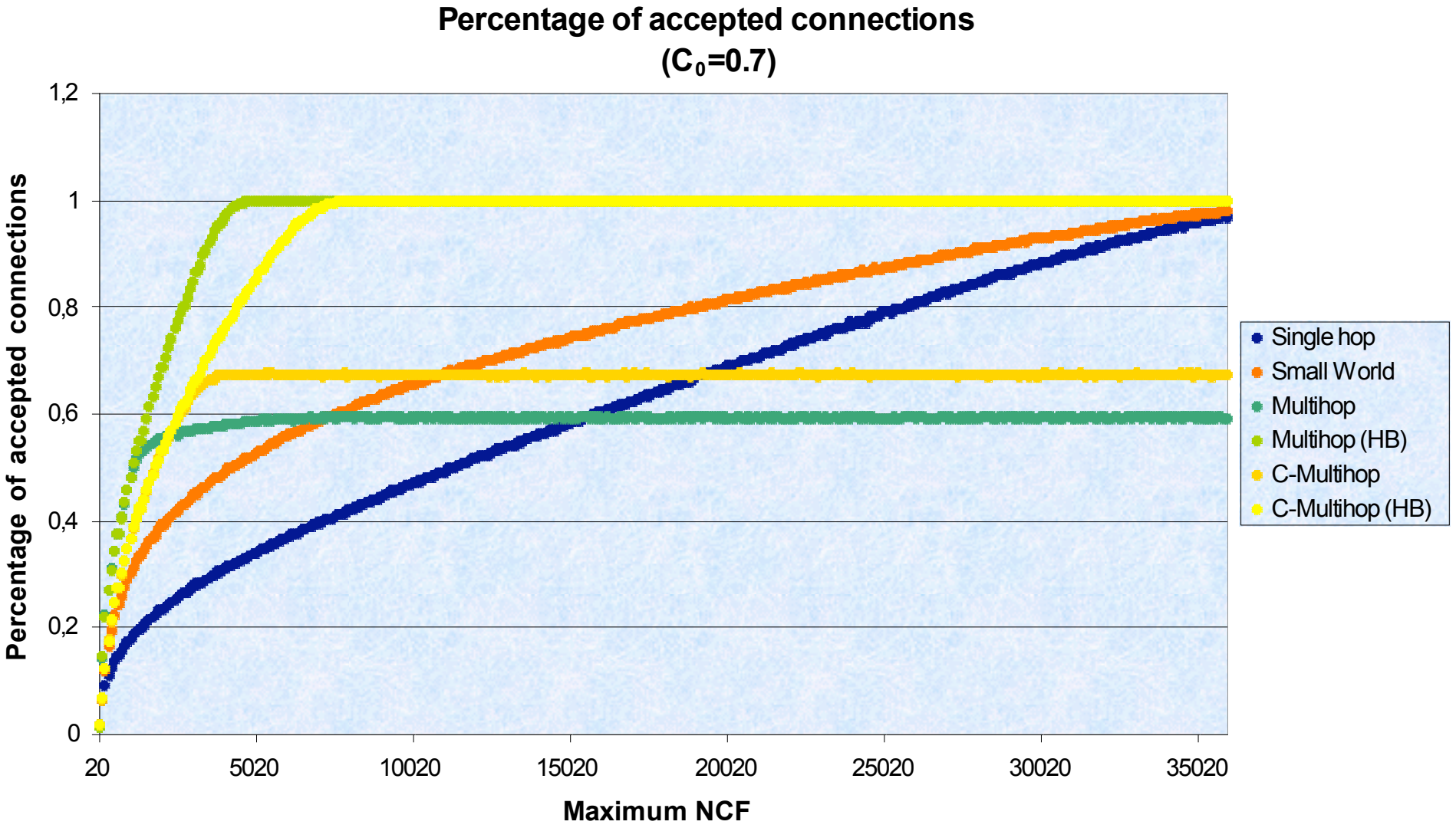
MultiHop and C-MultiHop algorithms:

- High Bandwidth plots: B increased of one order of magnitude in order to avoid saturation

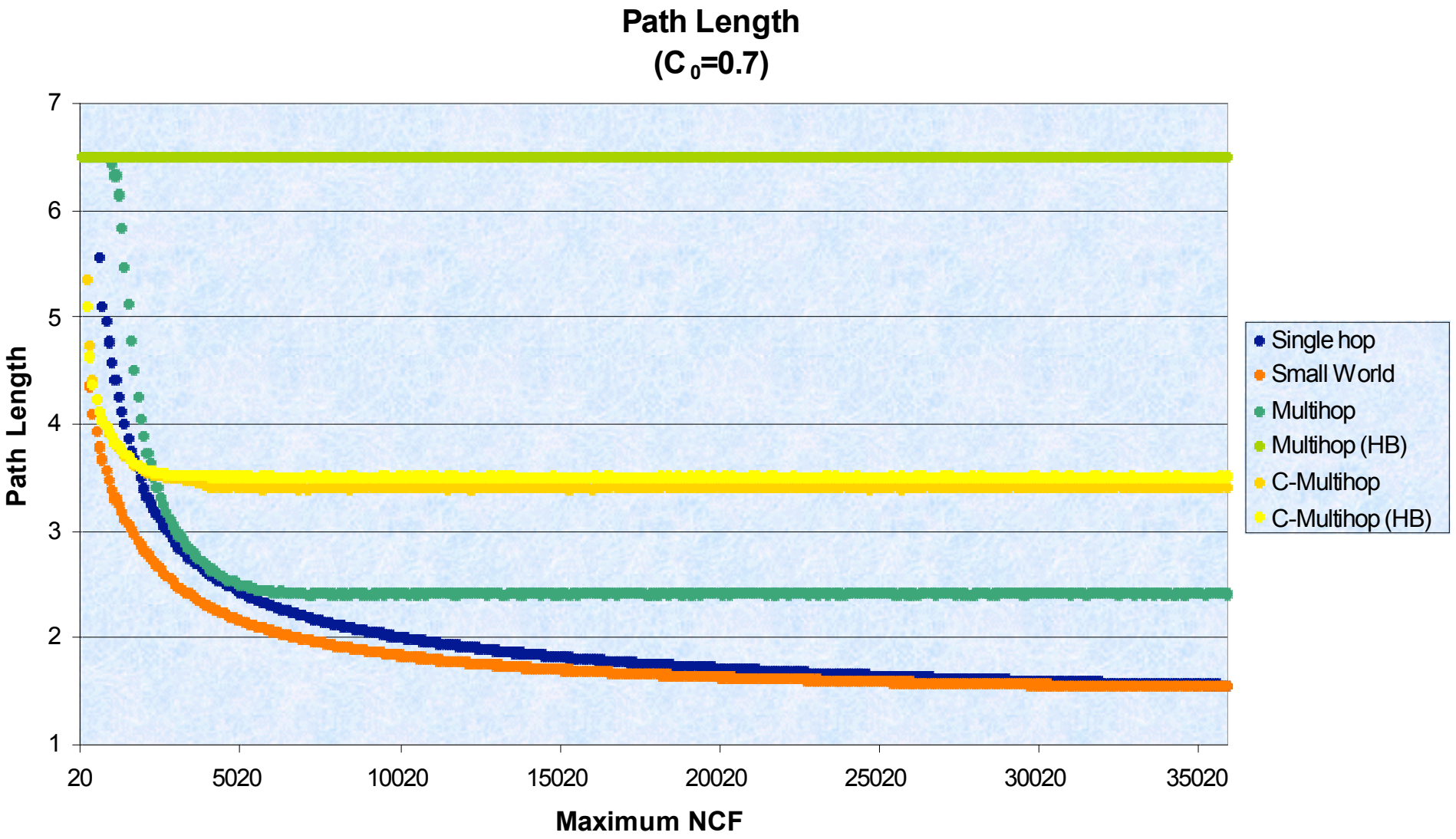
Average number of hops



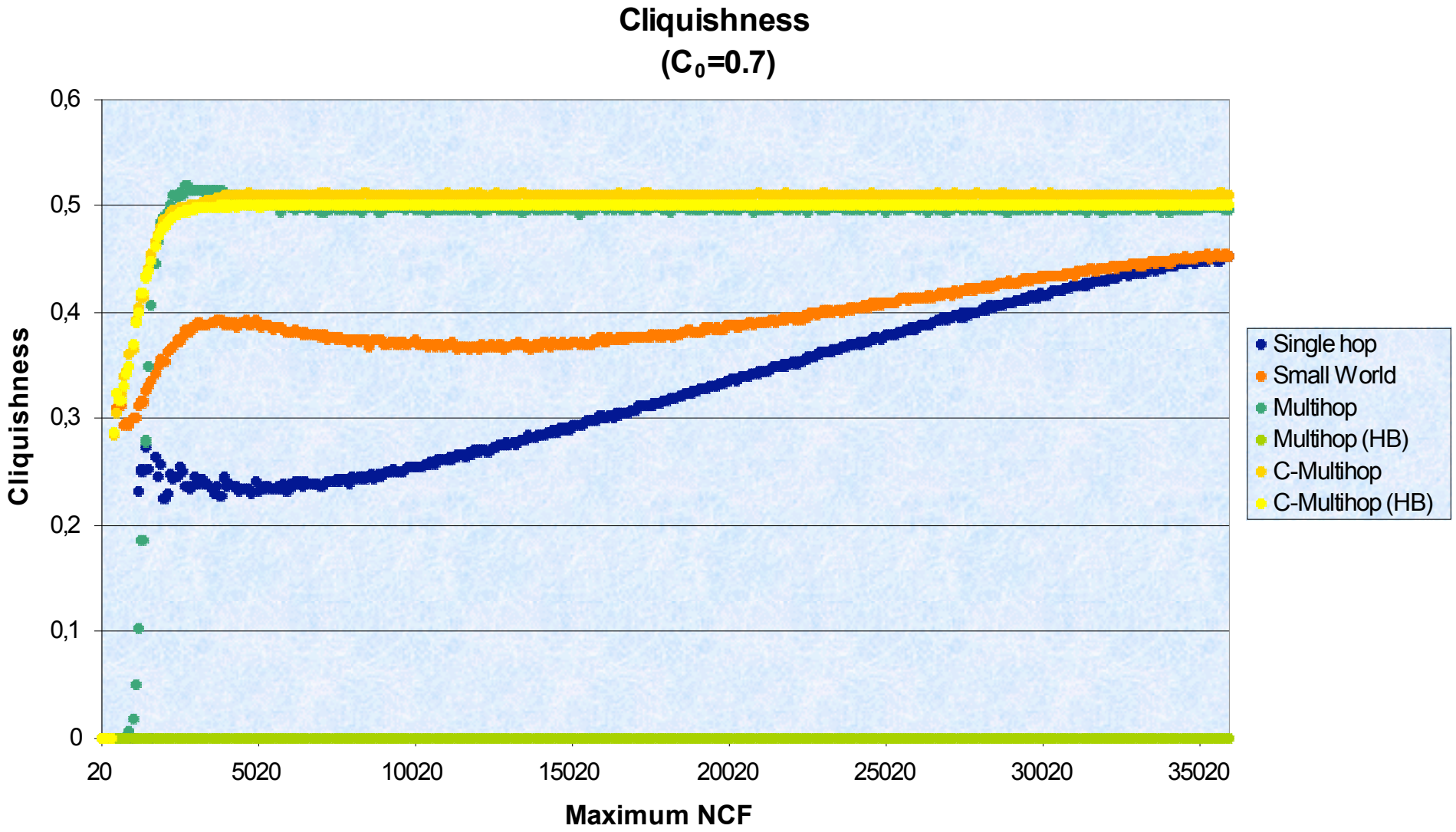
Percentage of accepted connections



Path Length


Path Length
(C 0=0.7)
Path Length
Maximum NCF
7
6
5
4
3
2
1
20
5020
10020
15020
20020
25020
30020
35020
Single hop
Small World
Multihop
Multihop (HB)
C-Multihop
C-Multihop (HB)

Cliquishness



Future work

- Expand the multi-hop self-organizing concepts to large-scale systems, by introducing the concept of logical visibility
- Introduce mobility in the model
- Further refine the cost function (introducing terms related to UWB internal interference, node reliability, congestion, number of hops…)
- Analyze the convergence of the network to a Small-World topology through a shortest path algorithm minimizing the Network Cost Function