Optimization of Control Signaling in 3G LTE

The problem and how to study it

Jonas Eriksson

Communication Systems

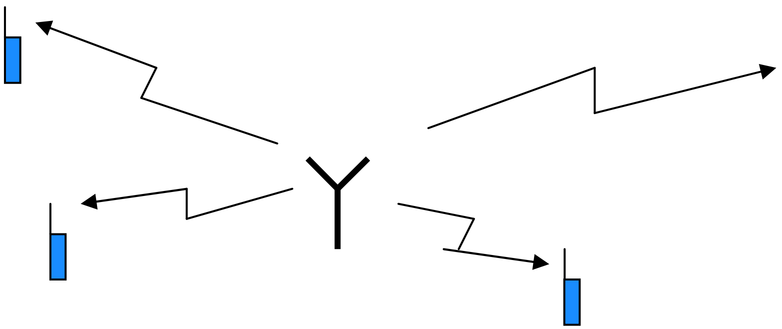
Outline

- Introduction
- Opportunistic scheduling
- The control signaling research problem
- 3G LTE channel structure
- Project objectives
- Research approach
- Simulation model
- Example of preliminary simulation results

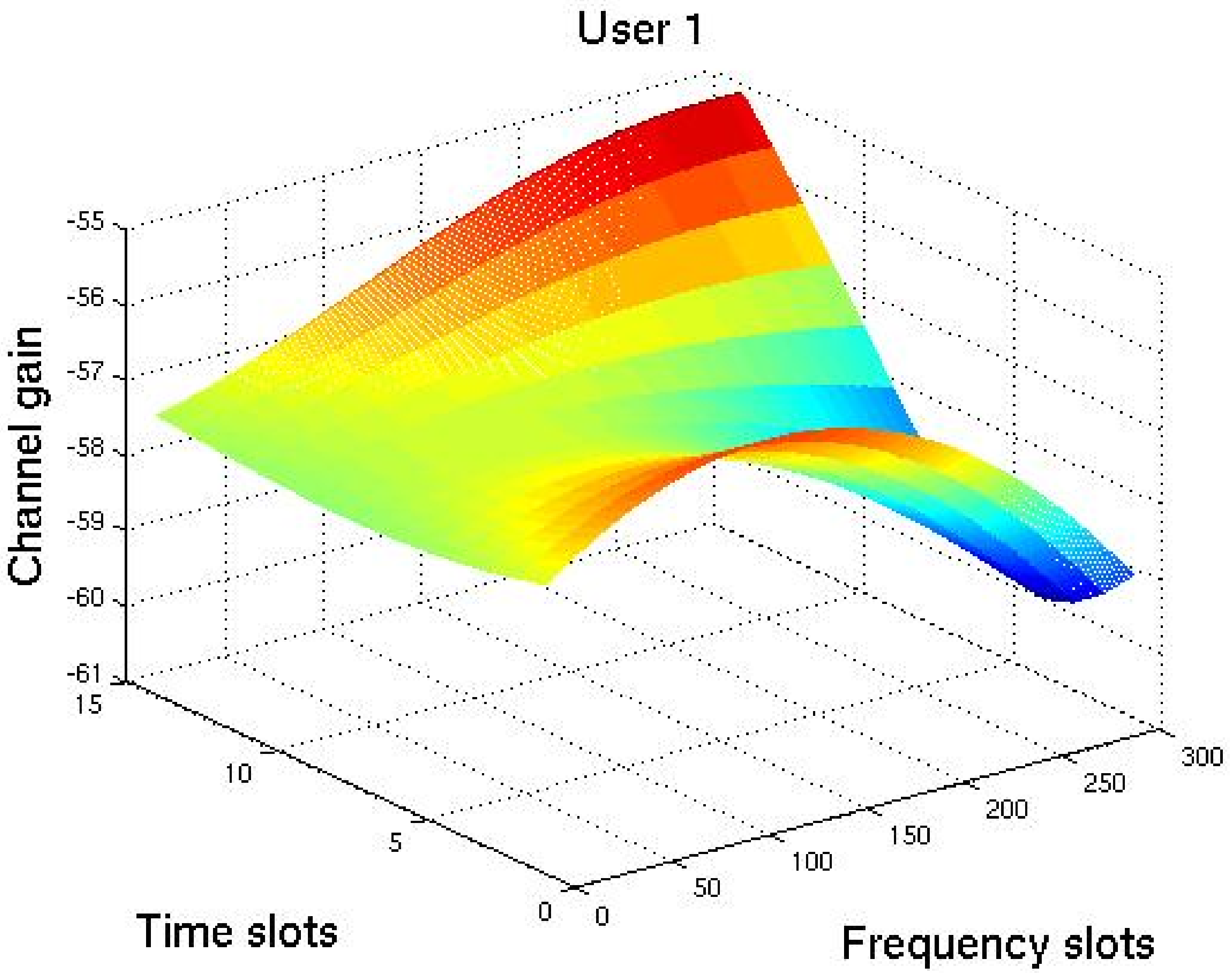
Control Signaling in OFDMA Systems

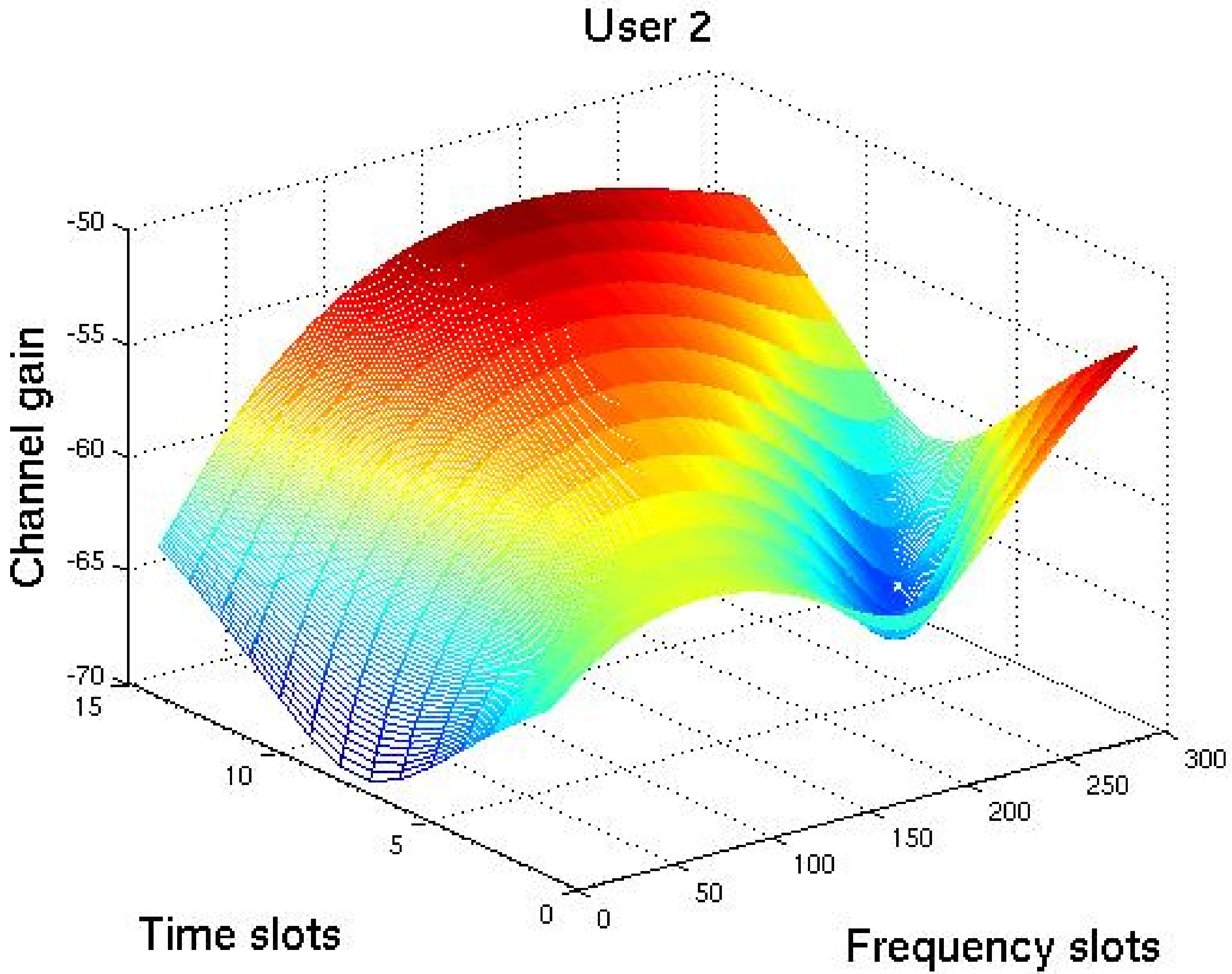
- The division of Communication Systems at Linköping University is cooperating with Ericsson Research in Linköping in a project studying the control channel of OFDM systems.
- OFDM is used/suggested in many wireless communication standards:
  - 3G Long Term Evolution
  - WiMAX
  - Ultra Mobile Broadband,
  - Mobile Broadband Wireless Access (MBWA) (IEEE 802.20)
  - …
- OFDM gives the possibility of frequency user scheduling which is advantageous for system performance when communicating over time varying frequency selective channels. (Mobile wireless communication)

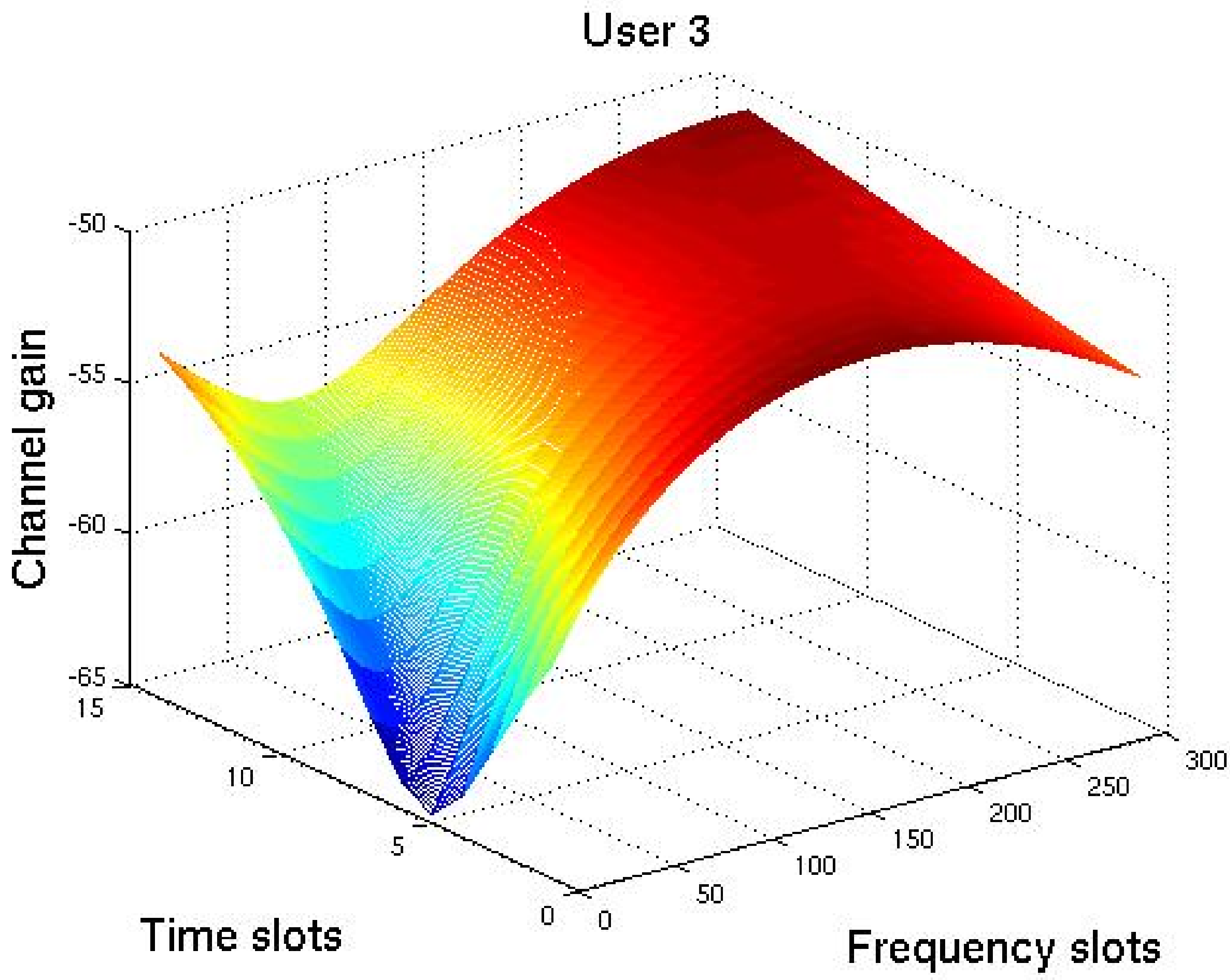
Time Varying Frequency Fading Channels

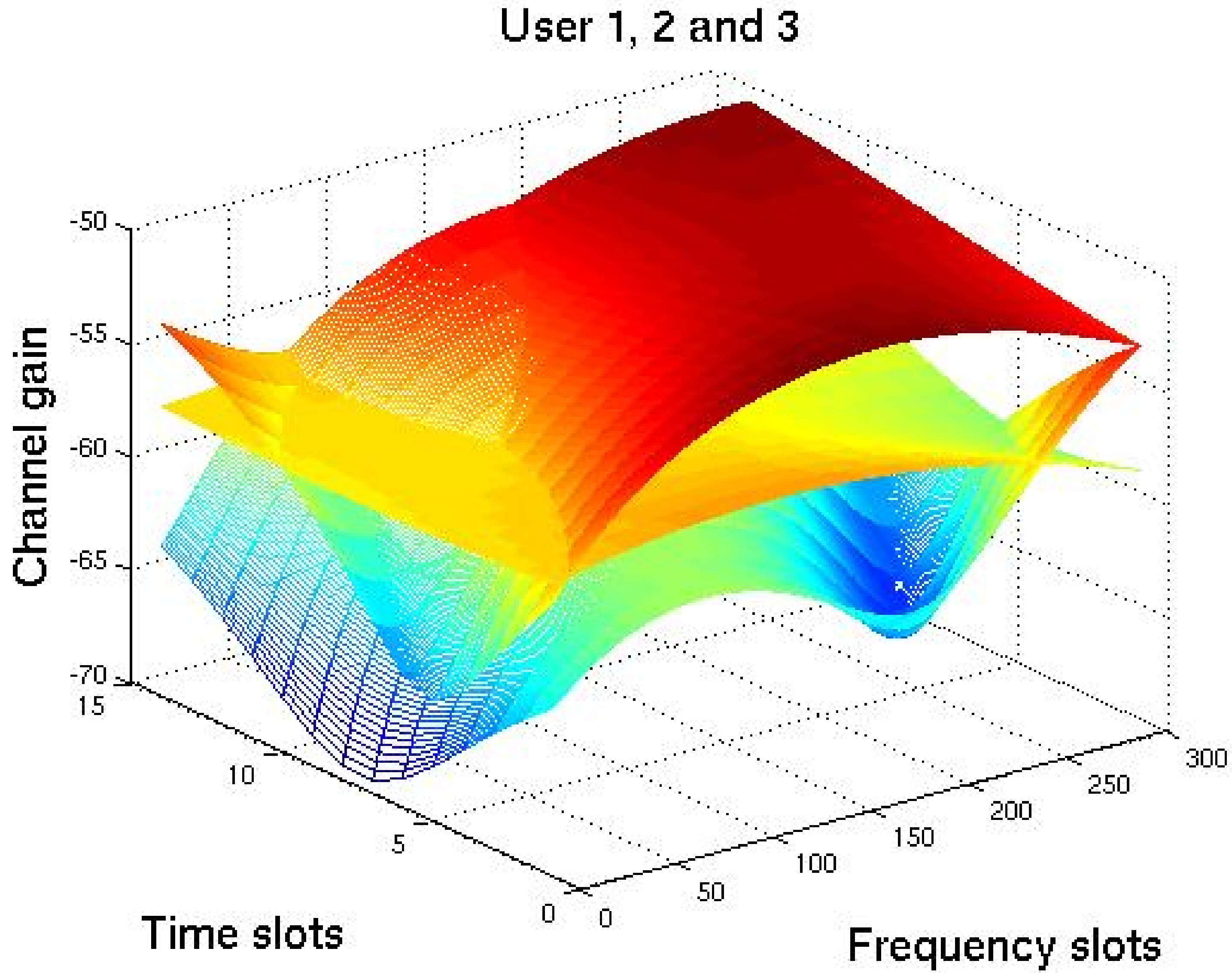


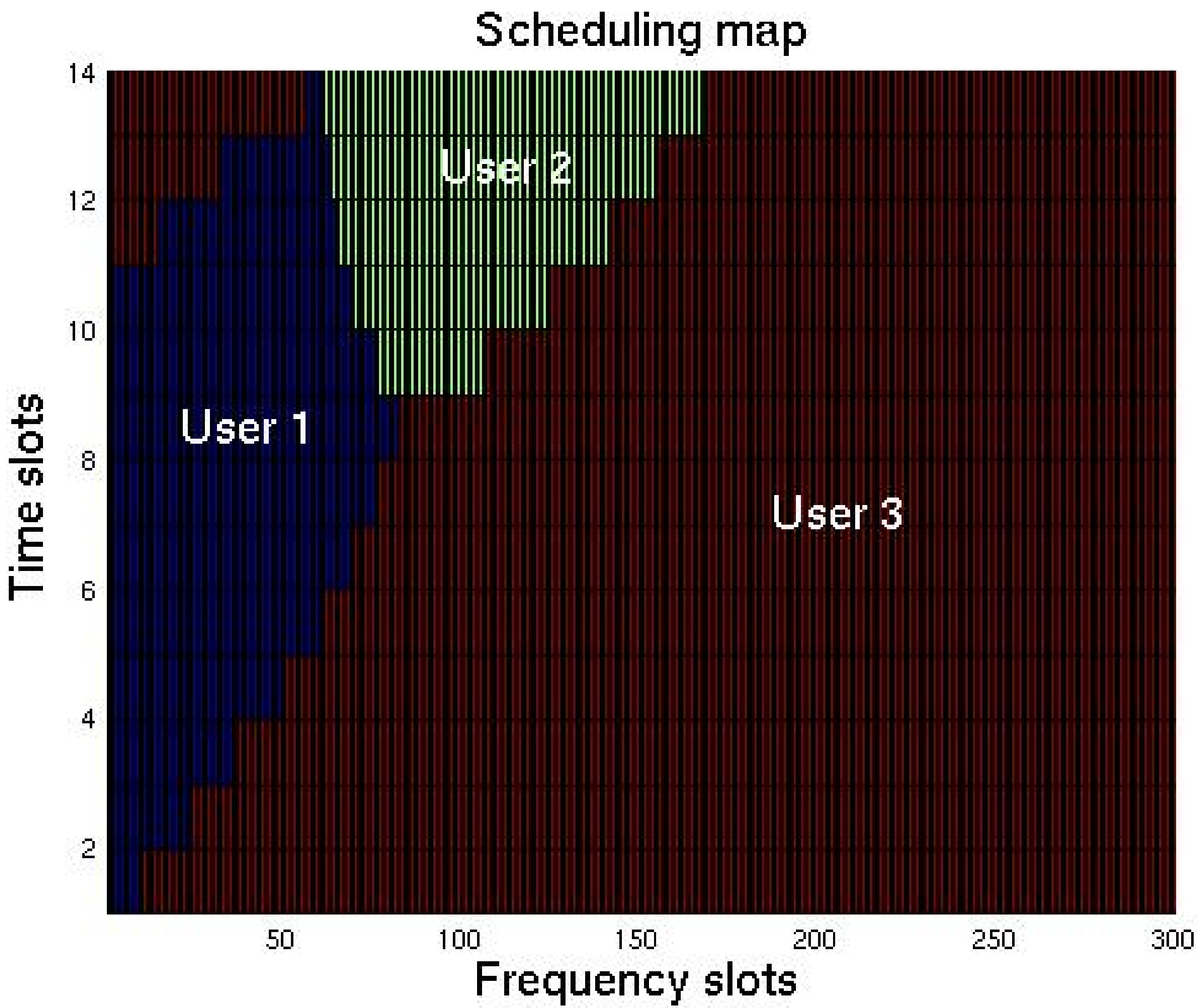
- Different mobile units experience the communication channel from the base station in their own way.
- The quality of these channels vary both in time and frequency.
- Multi-user diversity – Opportunistic scheduling to increase overall system performance.

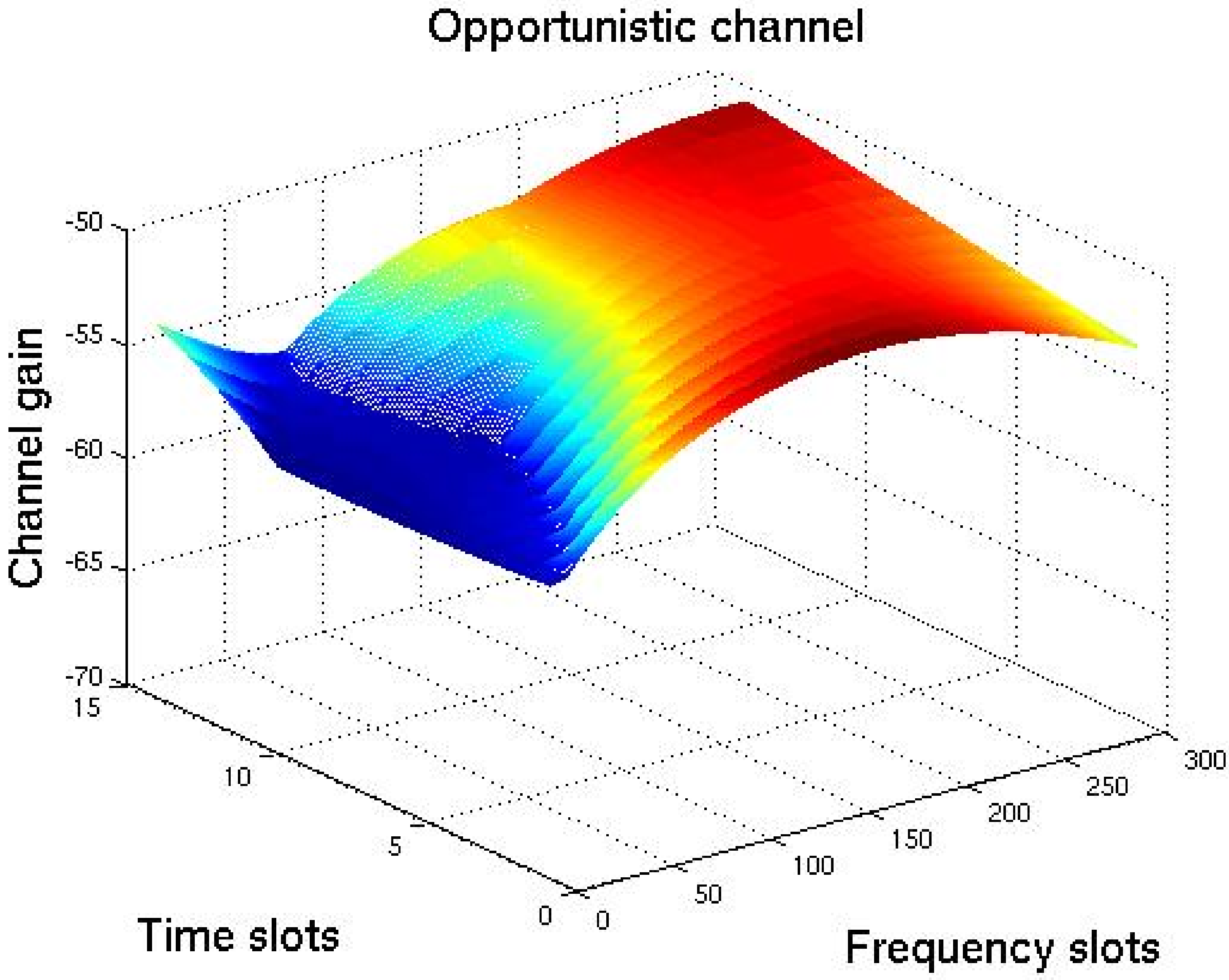

User 1
Channel gain
-55
-56
-57
-58
-59
-60
-61
15
10
5
0
Time slots
0
50
100
150
200
250
300
Frequency slots


User 2
Channel gain
-50
-55
-60
-65
-70
15
10
5
0
Time slots
0
50
100
150
200
250
300
Frequency slots


User 3
Channel gain
-50
-55
-60
-65
15
10
5
0
Time slots
0
50
100
150
200
250
300
Frequency slots


User 1, 2 and 3
Channel gain
-50
-55
-60
-65
-70
15
10
5
0
Time slots
0
50
100
150
200
250
300
Frequency slots

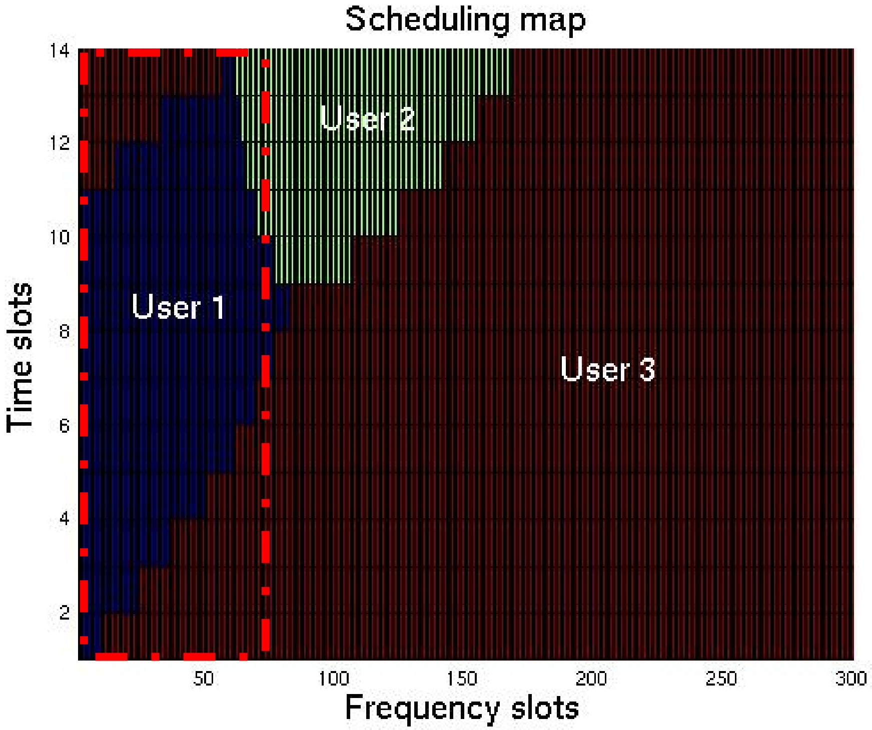

Scheduling map
User 1
User 2
User 3
Time slots
Frequency slots
14
12
10
8
6
4
2
50
100
150
200
250
300



Opportunistic channel
Channel gain
-50
-55
-60
-65
-70
15
10
5
0
Time slots
0
50
100
150
200
250
300
Frequency slots

Scheduling

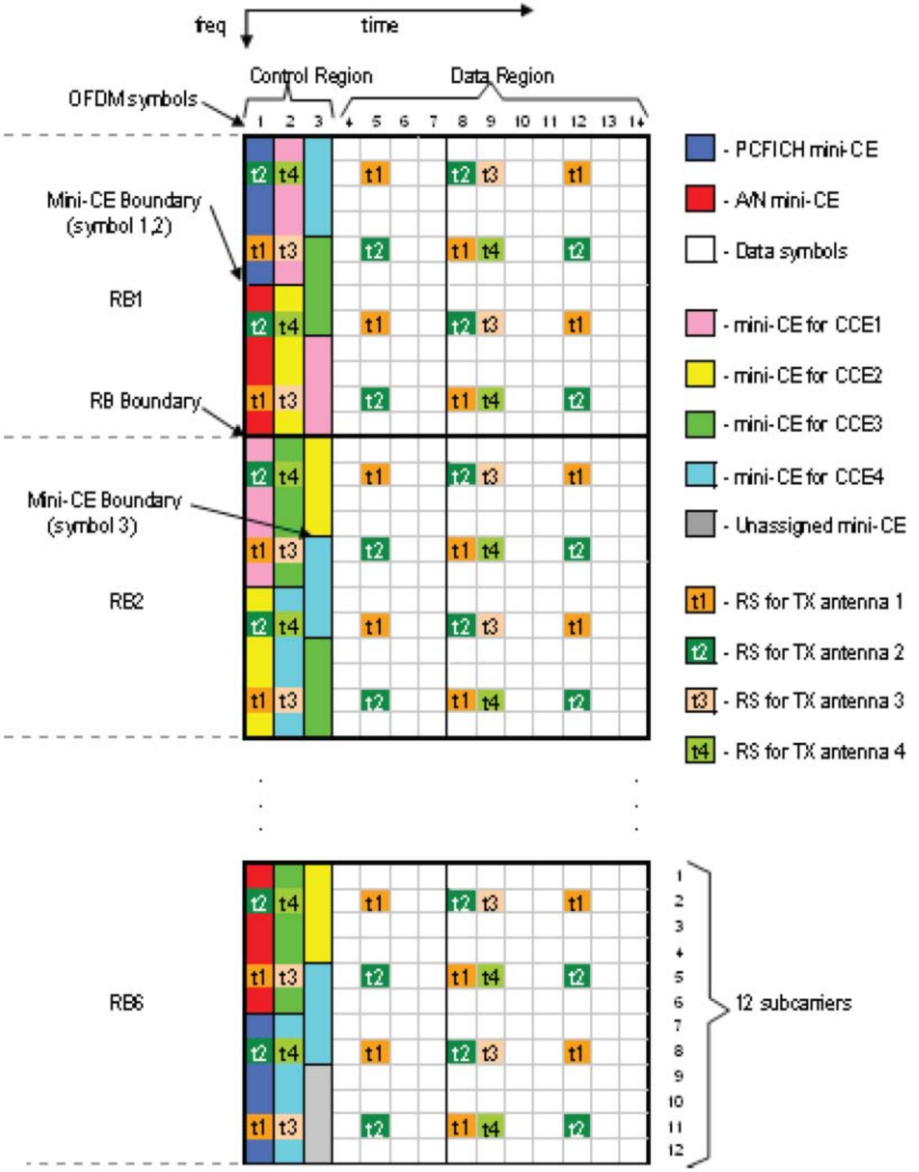
- Scheduling is done at the base station and scheduling decisions need to be *propagated* to the mobile units.
- Constitutes typically a substantial portion of the control information in an OFDM system.
- Control information *competes* with payload data for channel resources – reduces system performance.



Transmitting Control Information

- Conveying the control information to the mobile units need to be done in a robust fashion, but without spending to much channel resources.
- Broadcast channel - A specific mobile unit may potentially overhear the control information intended for the other mobile users and use it to its advantage when it is to receive its own.
- Control information intended for different mobile units is partly correlated.
  - Common control information.
  - Individual weakly correlated control information
  - Individual strongly correlated information (eg scheduling map)
- **How do we represent and transmit this mix of structured information effectively? What are the fundamental limits to the solution of the problem?**

3G LTE Channel structure



Project objectives

- Determine a good comparative measure for control signaling strategies for multiuser OFDM systems.
- Develop uncomplicated yet relevant simulation models for the purpose of he study.
- Study the fundamental limitations of the control signaling problem
- Suggest new strategies for efficient signaling of control/scheduling information in OFDM
- Evaluate different strategies using the suggested measure.
- Possibly contribute to future standards

Comparative measure

- We suggest using an approach for comparing different strategies based on an ergodic capacity idea.
- A resulting channel *S* produced by the scheduler provides a certain capacity according to

$$C(S) = \max_{\sum_{i,j} P_{i,j} \leq P} \left\{ \Delta_f \cdot \sum_{i,j} \log \left(1 + \frac{P_{i,j} |s_{i,j}|^2}{\Delta_f N_0} \right) \right\}$$

- The optimal power allocation is obtained by classical waterfilling.
- This expression is empirically averaged over a large number of channel realizations.

Comparative measure

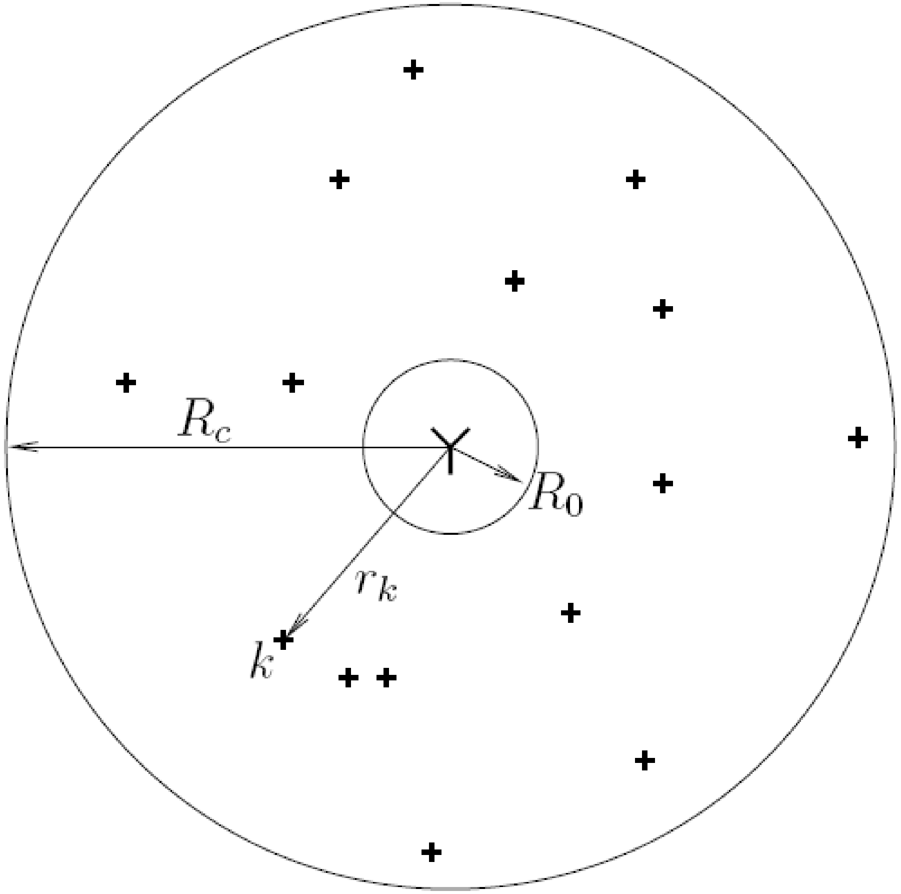
- The basic idea to cost setting the signaling of scheduling information on the control channel is:
  - Calculate a bit cost for transmitting a specific scheduling decision
  - Map the bit cost into channel resource cost by omitting the number of time/frequency slots needed to convey the information from the summation in the capacity formula.
- The bit cost will depend on many parameters.
- The mapping of the bit cost into channel resource cost can be done in many ways.

Simulation model

- The project aims at studying the control channel structure using Monte Carlo simulations.
- A fairly clean, transparent and straightforward model is desirable.
- A model written in C++ based on the IT++ libraries is being developed.
- Key components:
  - Cell population model
  - Channel model (OFDM setup, fading processes)
  - Scheduling algorithms
  - Control signaling strategies
  - Cost measure

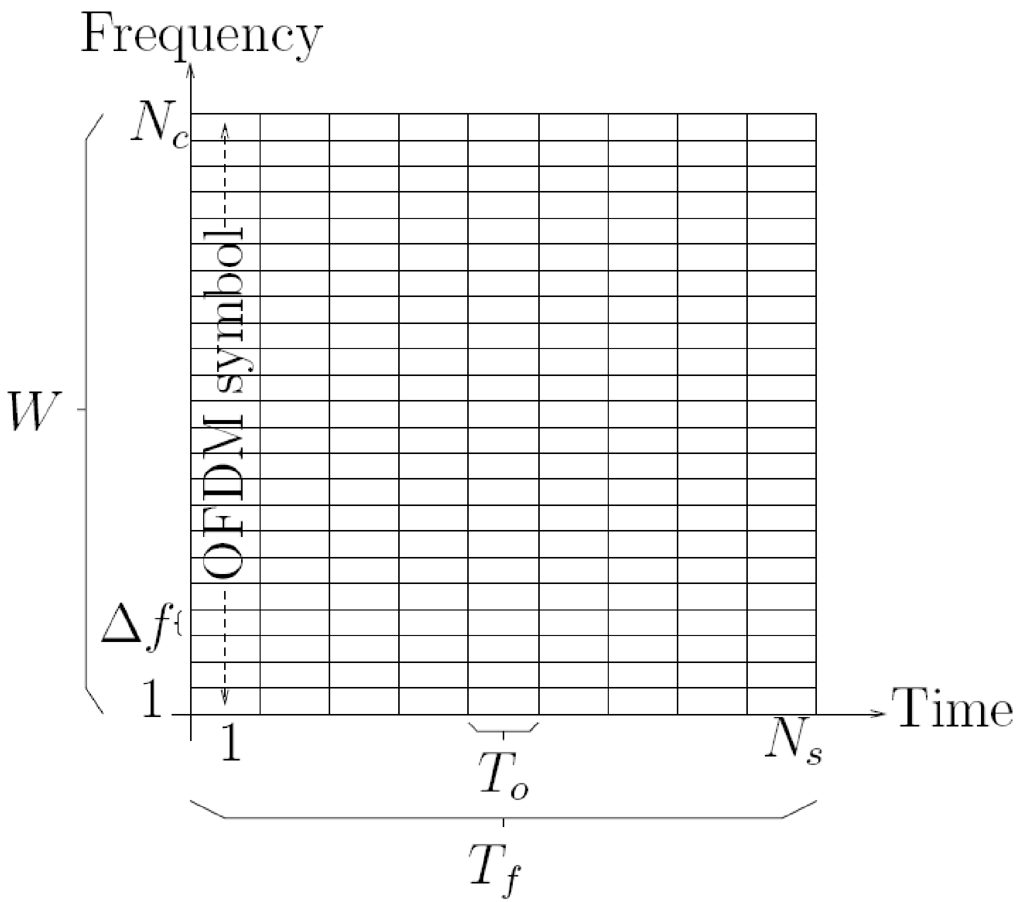
Cell population

- A simple drop model for uniformly distributed mobile users in a donut shaped cell.



Channel modeling

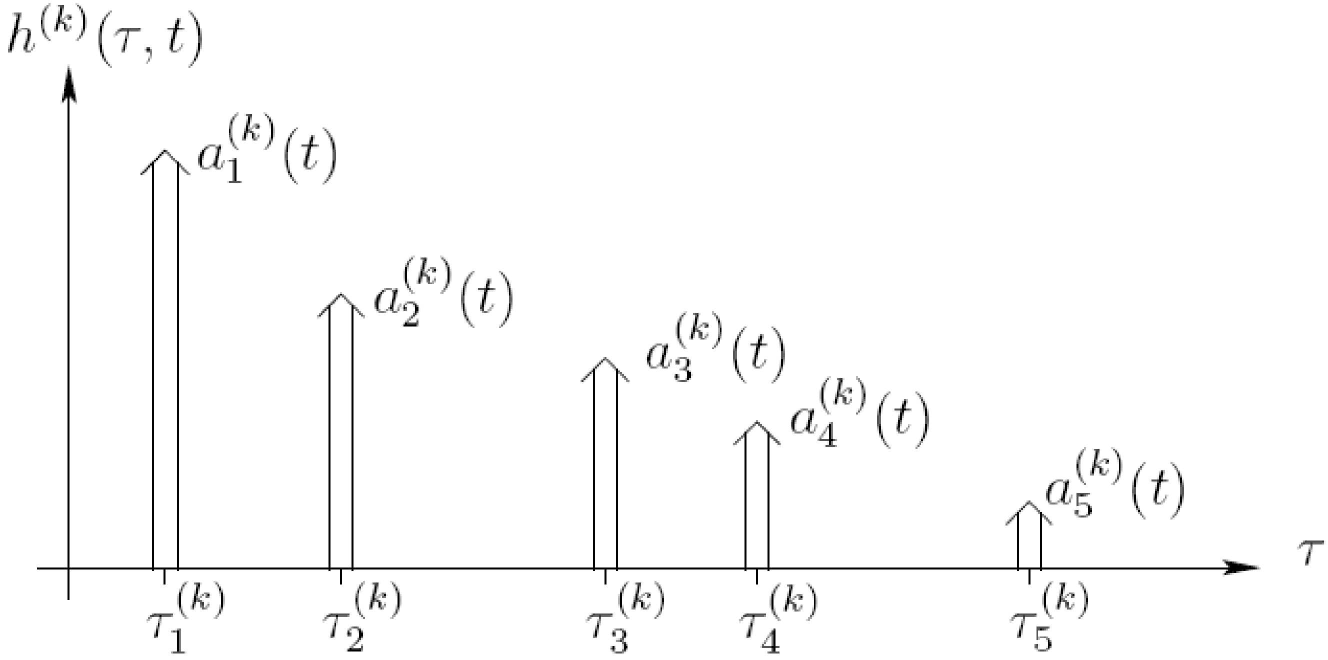
- OFDM parameters define the time/frequency grid



Channel modeling

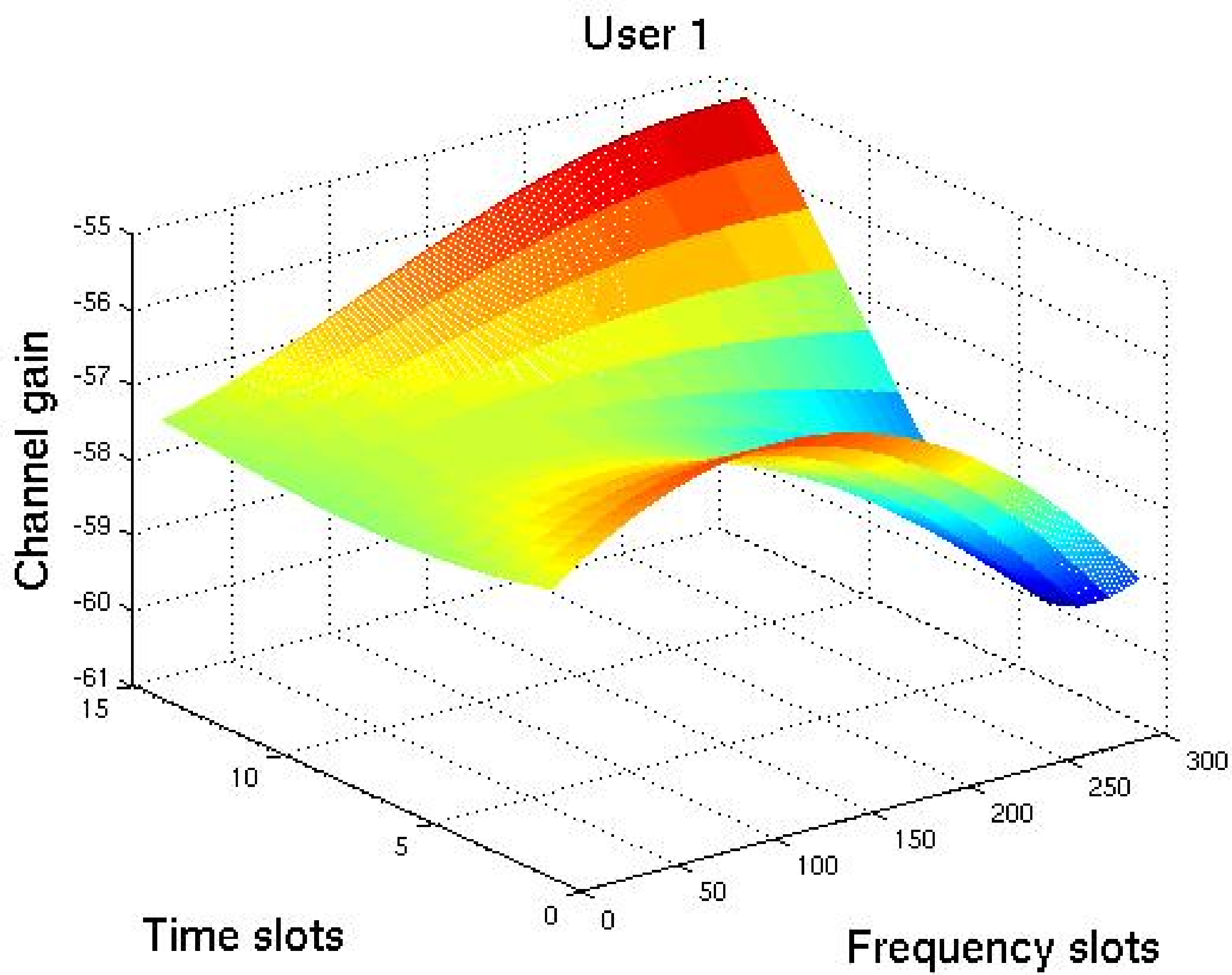
- Small scale fading is modeled by a tapped delay line

$$h^{(k)}(\tau, t) = \sum^{N_t} a_i^{(k)}(t)\delta(\tau - \tau_i^{(k)})$$



Channel modeling

- Three tapped delay line setups are used
  - ITU Pedestrian A
  - ITU Vehicular A
  - Custom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-61
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5
0
0
50
100
150
200
250
300
Time slots
Frequency slots

Channel modeling

- Large scale fading is modeled by path loss and shadowfading factors:

$$(r_k/R_0)^{-\alpha} 10^{\frac{\chi}{10}} \qquad \chi \sim N(0,\sigma)$$

Scheduling algorithms

- Three different scheduling principles are so far aimed for inclusion in the framework of the study
  - System maximizing
  - Round robin
  - Proportional fair

Control signaling strategies

- The aim of the project is to develop and study several control signaling strategies. Implemented so far:
  - Magic genie – Signaling without any resource cost at all.
  - Compress and broadcast – Assume near entropy reaching compression of the scheduling map and that the same information is broadcast to all scheduled users jointly.
  - LTE0 – One signaling/scheduling principle in the LTE standard based on transmitting scheduling bit vectors separately to each user. The bit vectors refer to scheduled resource blocks.
  - LTE0 + Hierarchical coding – Straightforward modification of LTE0 where scheduling bit vectors referring to previously sent bit vectors are transmitted separately to each user.

Cost measure

- The mapping of a bit cost for a scheduling decision into a channel resource cost can be done in several ways
  - Uncoded & Error free
  - Coded and with Errors
  - Fixed modulation
  - Enough capacity
- There are advantages and disadvantages with all of them from a study point of view.

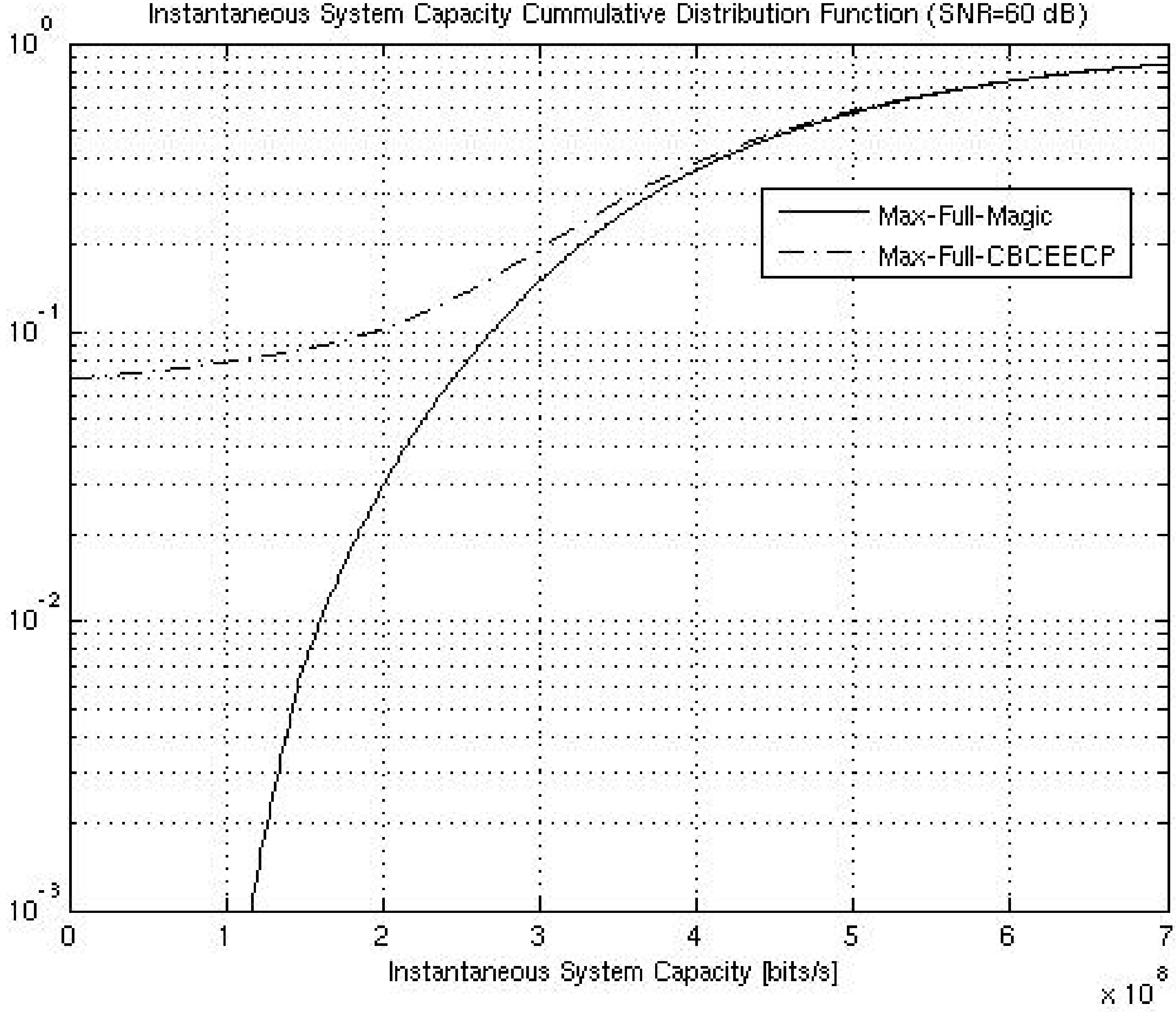
Initial system model restrictions

- Noise limited system
- Full channel knowledge
- Single antenna
- Maximum load scenarios

Preliminary simulation results

- Small example study: How does scheduling granularity affect system performance when the cost of signaling scheduling information is accounted for?
- System performance should in principle be better for systems with finer scheduling granularity, but the gain come at the cost of increased control signaling. Does the gain survive the cost?
- Comparison of three different scheduling granularities:
  - Full granularity – By individual time/frequency slot user scheduling.
  - Minimum granularity – All slots to one single user
  - Basic LTE granularity – User scheduling over LTE resource blocks
- System maximizing scheduler, custom three tap channel model, 200 Hz doppler spread, Jake's spectrum, cell population Bin(0.2,100), 1500 m cell radius. Path loss parameter α=4, shadowfading parameter σ=6 dB. Magic genie and Compress and Broadcast ('worst channel' measure)

Preliminary simulation results



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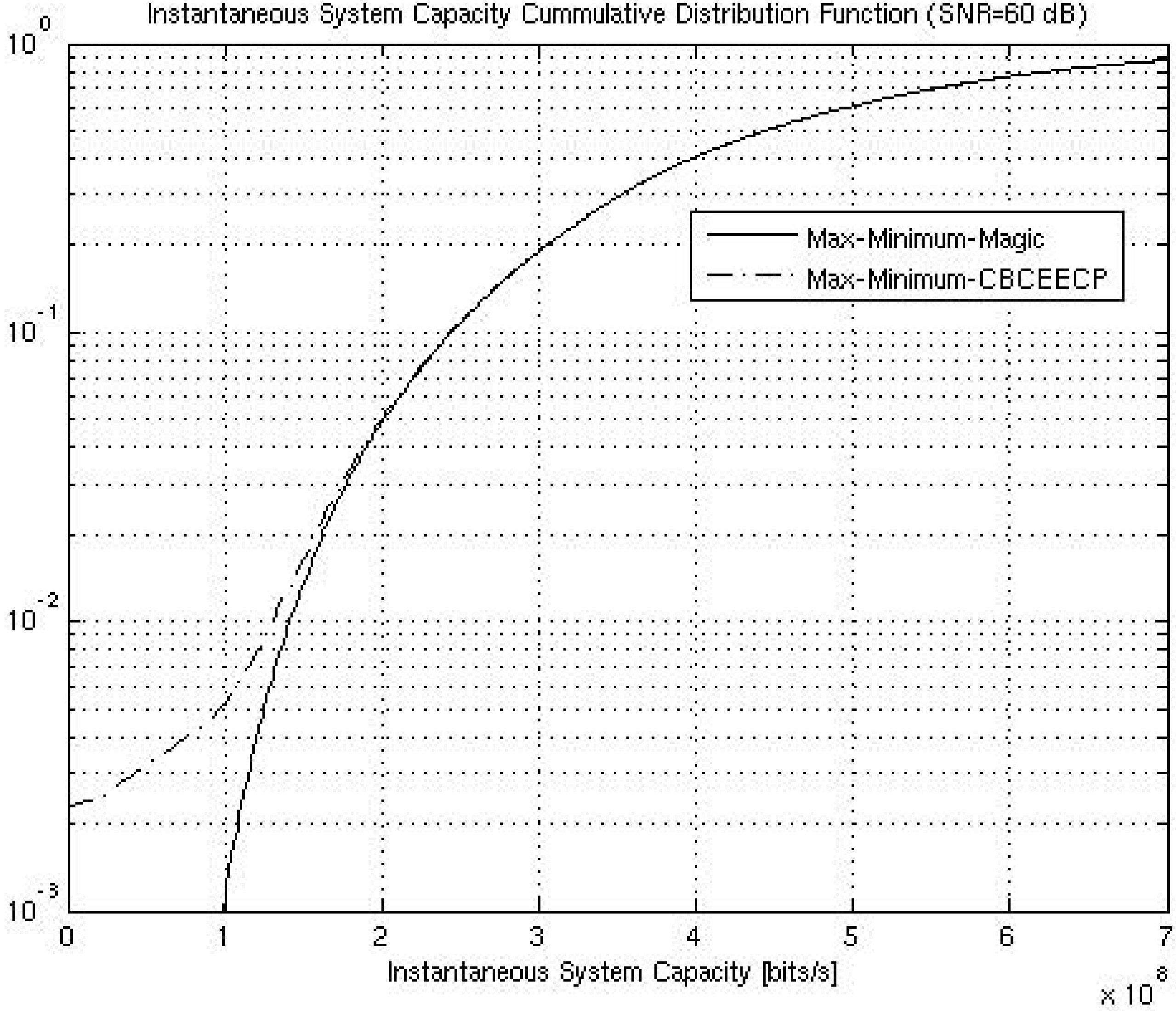

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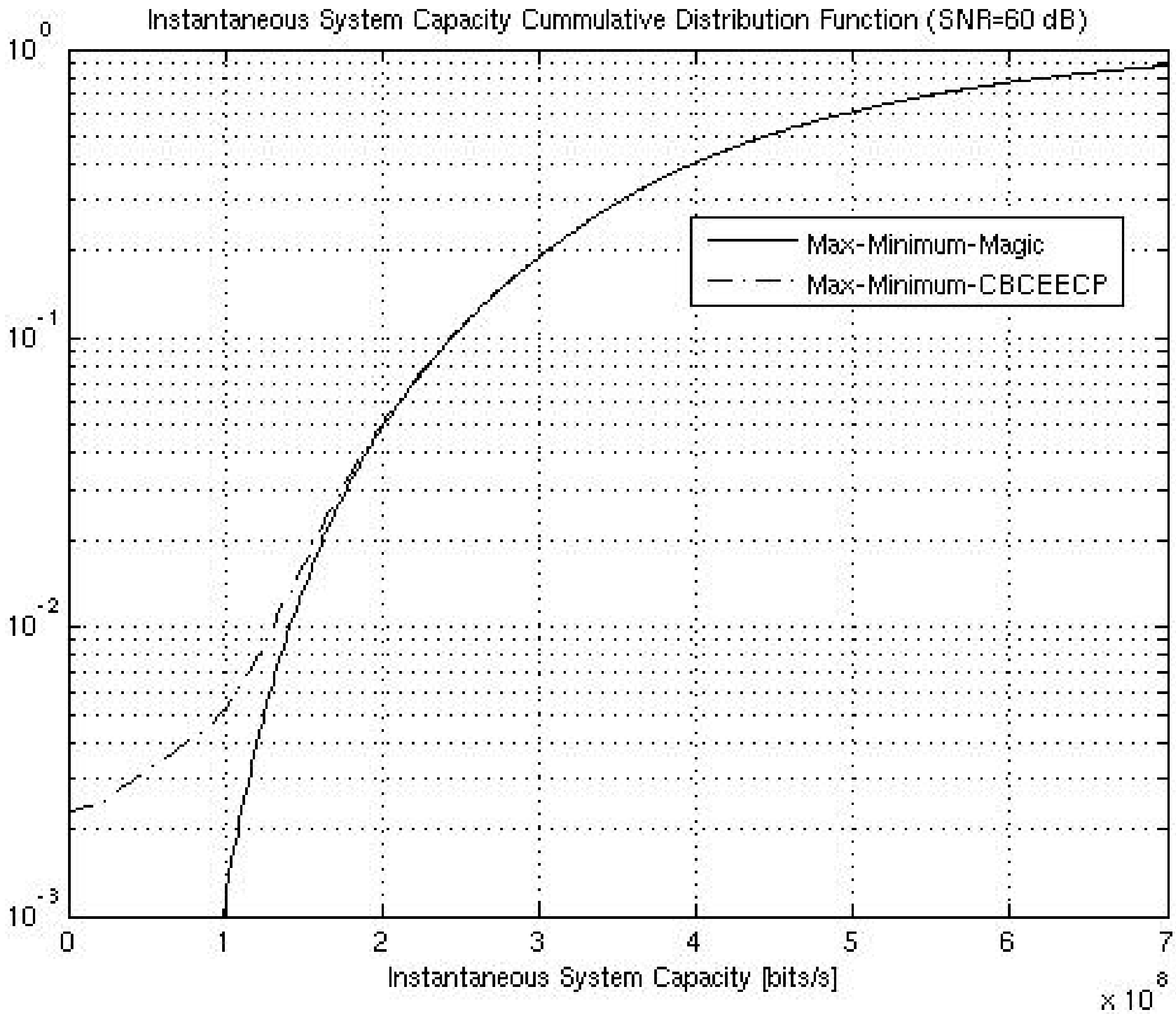

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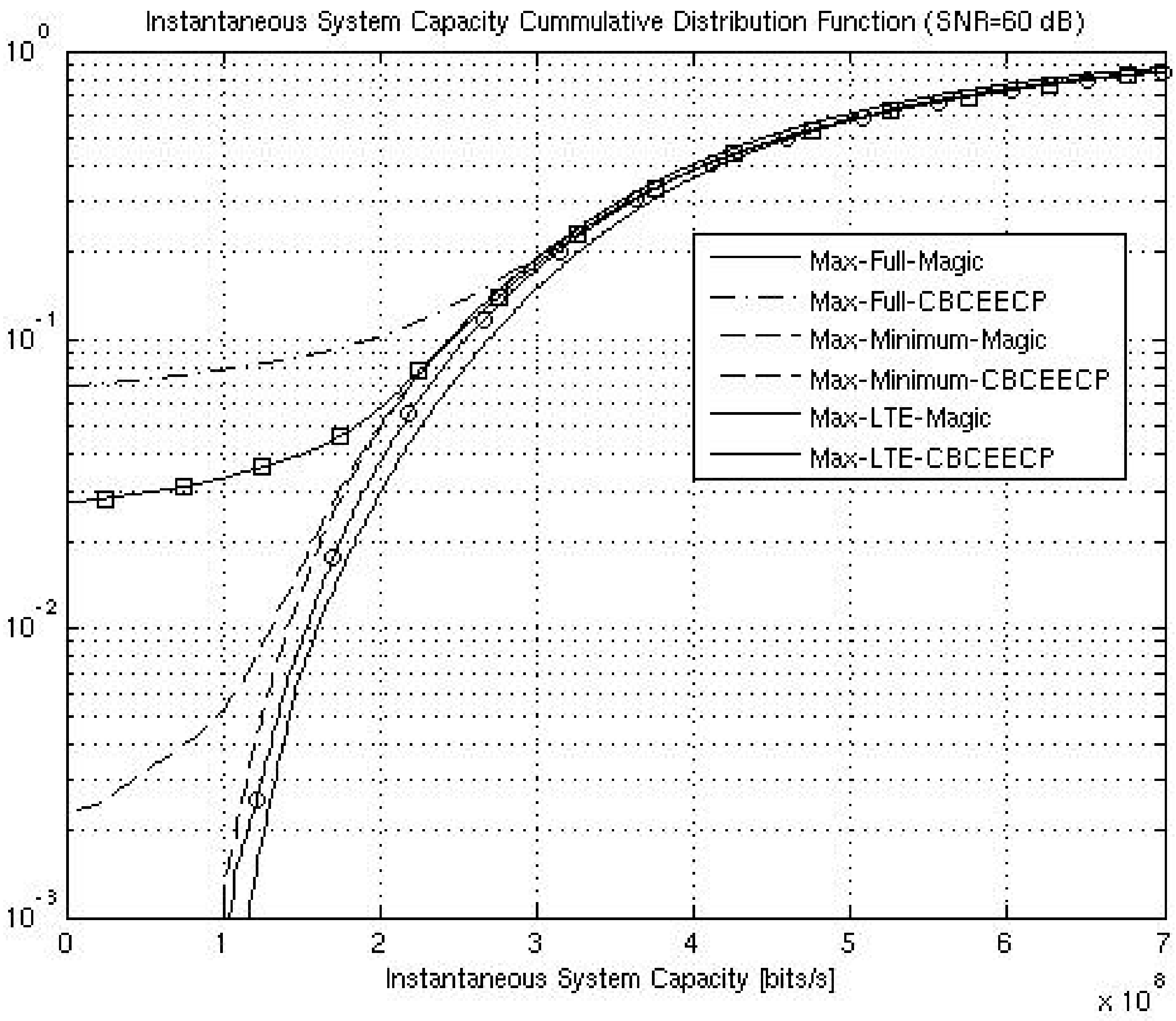

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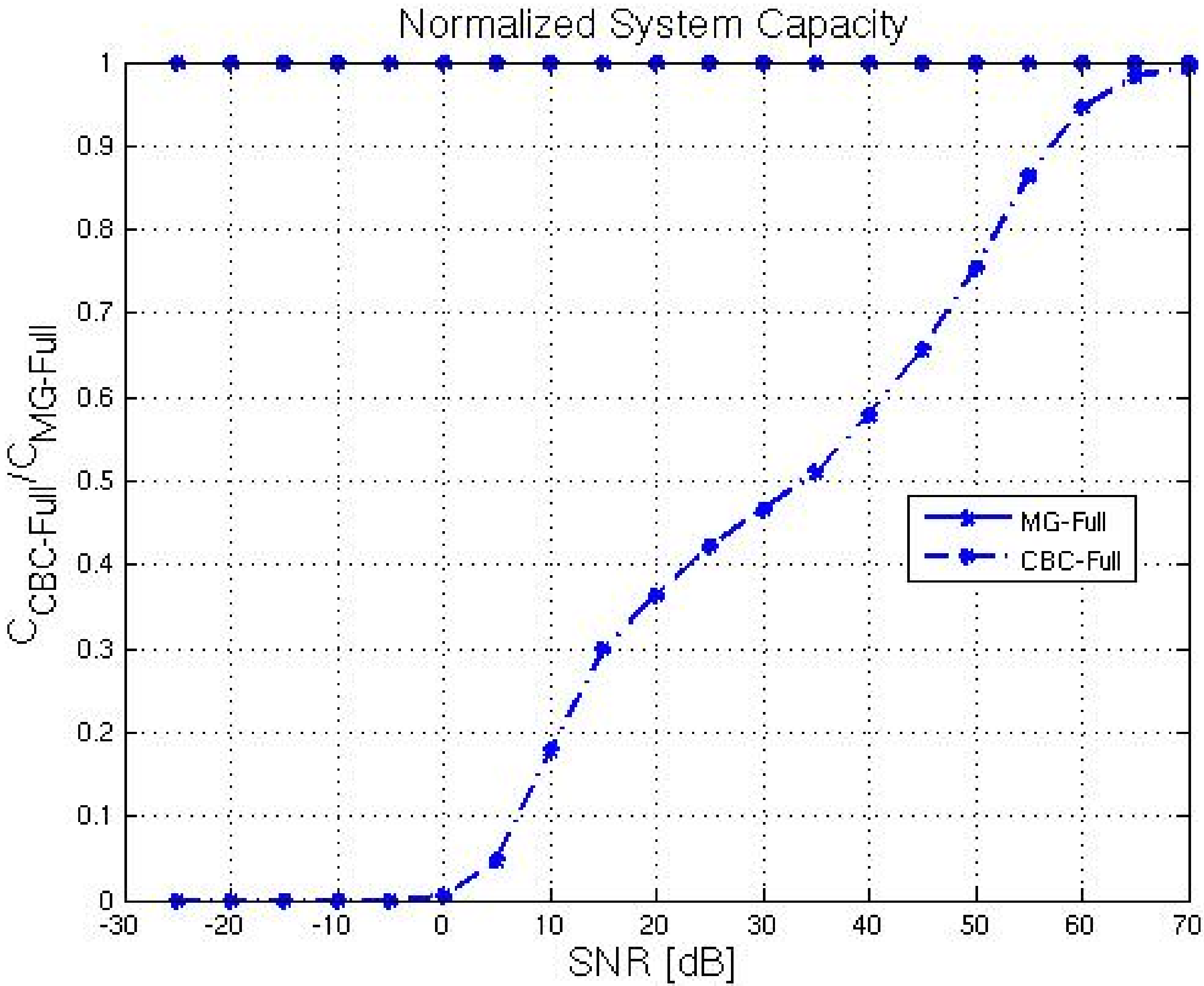

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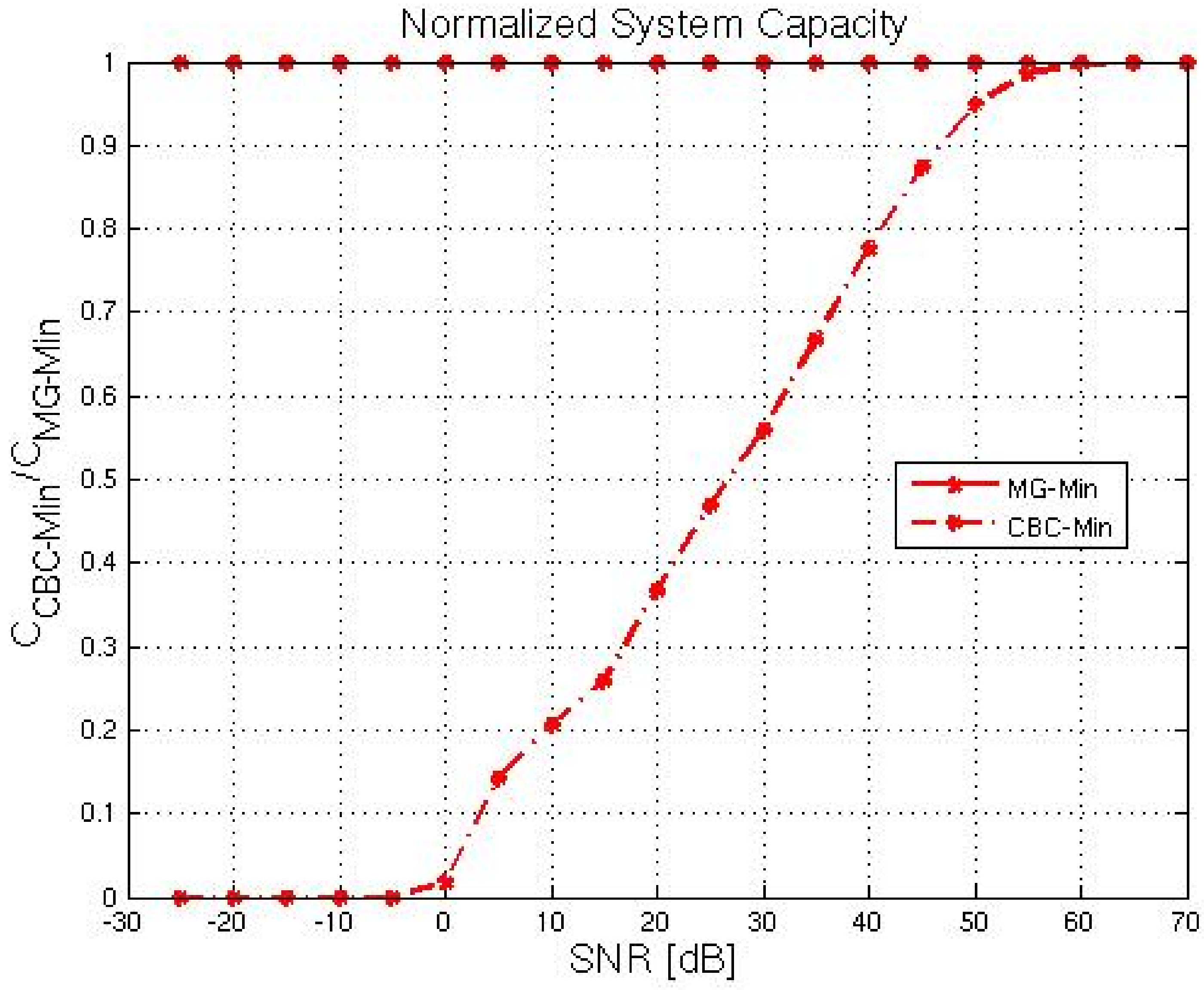

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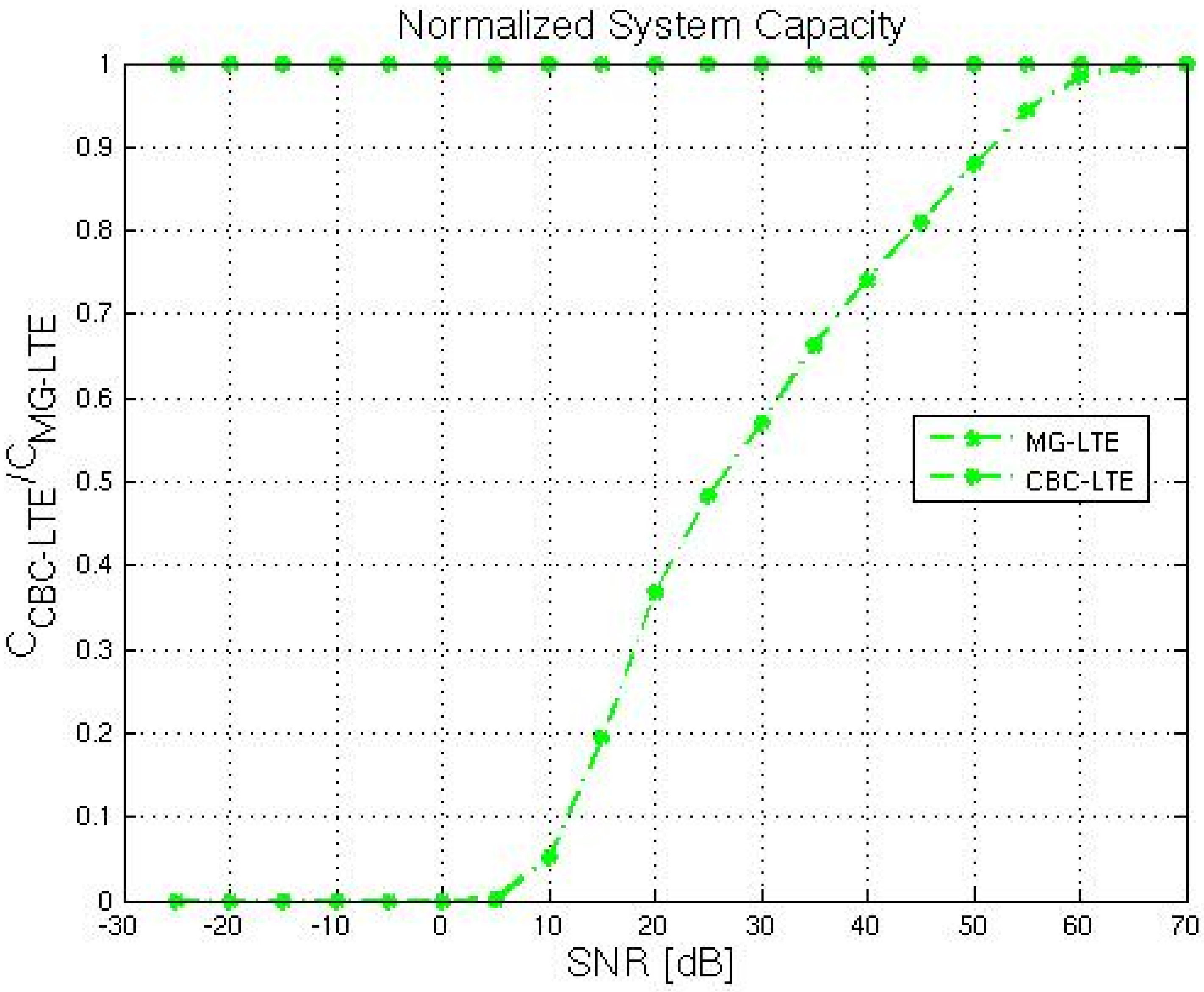

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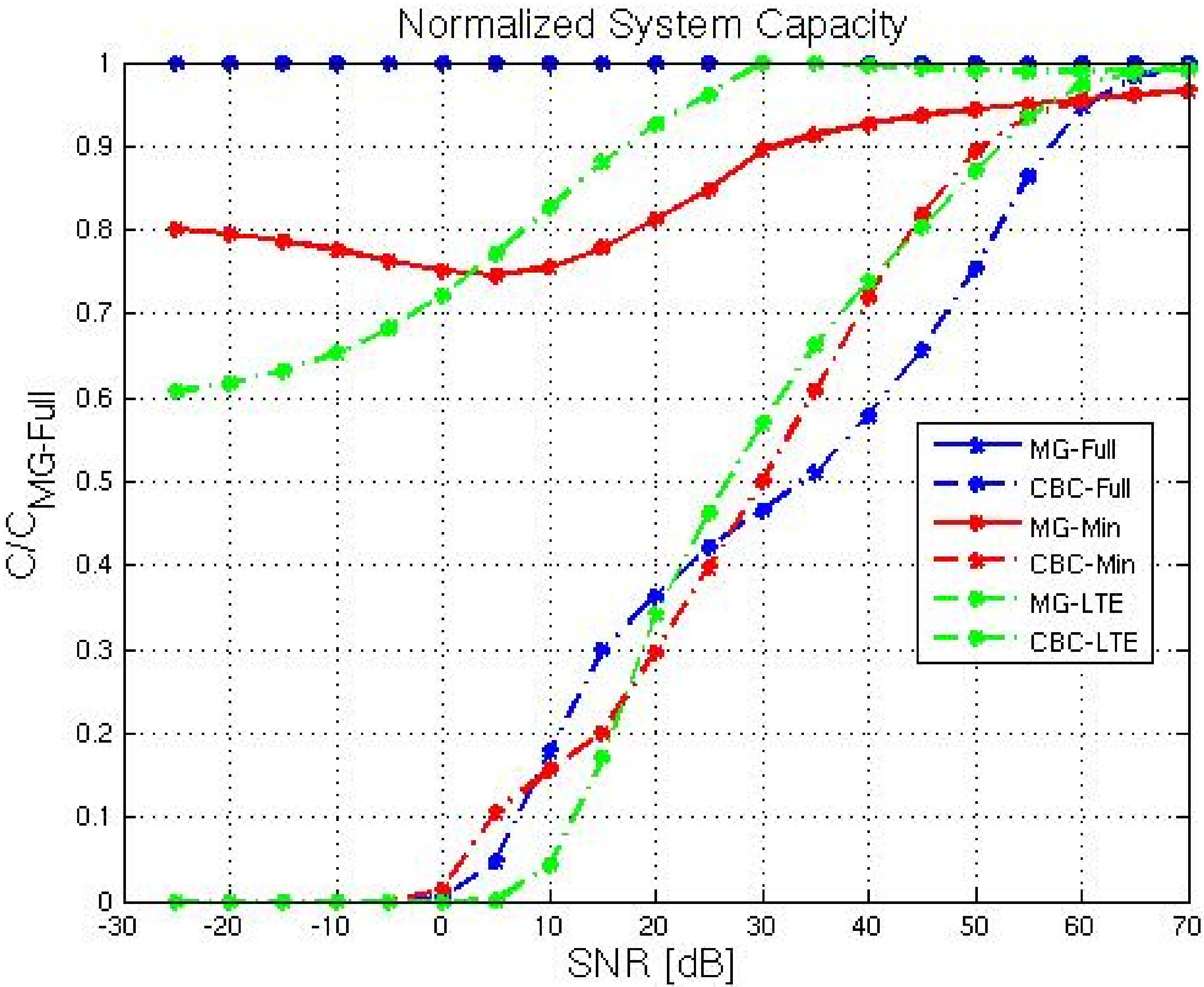

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