RRA

Vehicular Communications – Part II
Radio Resource Assignment

Roberto Verdone
www.robertoverdone.org

Outline

1. Radio Resources
2. Assignment of Radio Resources
3. Area Coverage Networks
4. Reuse
5. Radio Resource Management

The scope of this lecture block is to introduce a general definition of Radio Resource Unit, and the basic algorithms and protocols used in mobile radio networks for the management of radio resources.

1. Radio Resources

Radio Resources

Medium Access Control (MAC) and Radio Resource Control (RRC)

Both MAC and RRC address the problem of assigning radio resource units to data blocks in a shared radio environment, at a different pace

Radio Resource (RR)

A *radio waveform* allowing the transmission of a given data block (m bits)

Radio Resource Payload

Amount of information bits (as seen by data link layer) carried by the radio resource

Radio Resource Unit (RU)

A RR carrying the minimum value of Radio Resource Payload that can be assigned

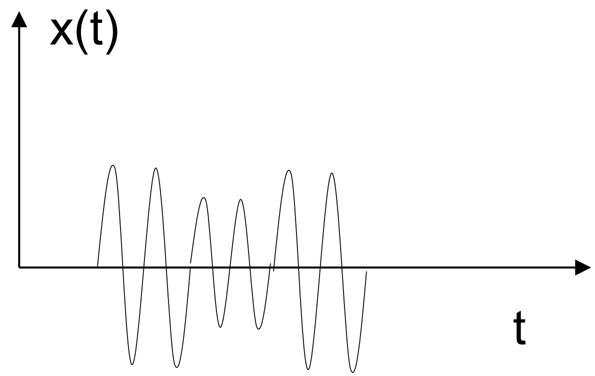
The scope of RR Assignment is to maximise the exploitation of the available RUs while fulfilling Quality of Service (QoS) requirements:

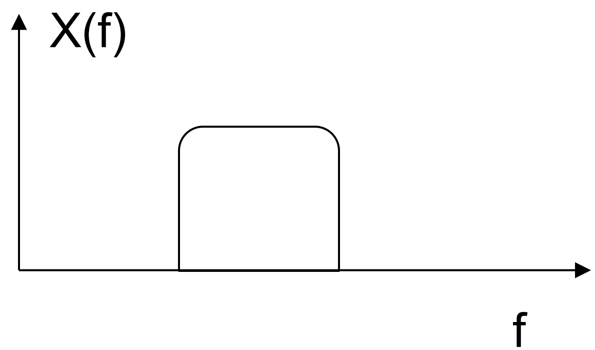
tradeoff between *network* spectrum efficiency and QoS

Radio Resources

The RU assignment implies the definition of all characteristics of the radio waveform.

From the signal viewpoint:





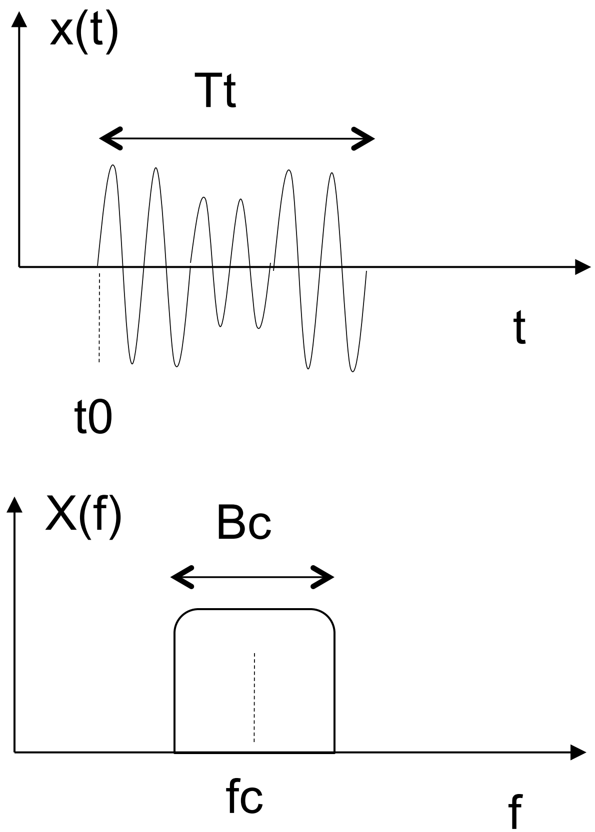
RU = [?]

Radio Resources

The RU assignment implies the definition of all characteristics of the radio waveform.

From the signal viewpoint:

- energy level (E),
- modulation and coding scheme (MCS),
- carrier frequency (fc),
- start time (t0),
- duration (Tt),
- bandwidth (Bc).



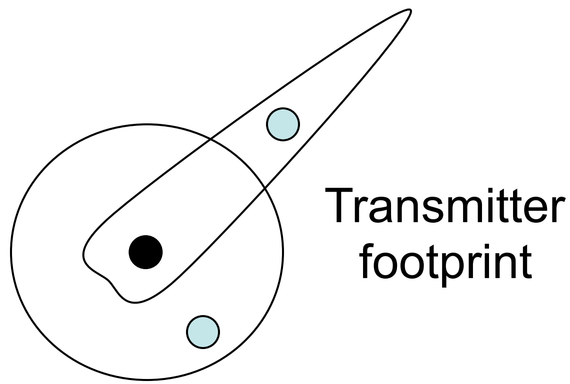
RU = [E, MCS, fc, t0, Tt, Bc]

Radio Resources

The RU assignment implies the definition of all characteristics of the radio waveform.

From the *radio* signal viewpoint:

- energy level (E),
- modulation and coding scheme (MCS),
- carrier frequency (fc),
- start time (t0),
- duration (Tt),
- bandwidth (Bc),
- antenna pattern (Ga)



RU = [E, MCS, fc, t0, Tt, Bc, Ga]

Radio Resources: Bi-directionality

FDD (Frequency Division Duplexing)

The two links use different frequency bands (e.g. GPRS)

RU = [E, MCS, fc, t0, Tt, Bc, Ga]

TDD (Time Division Duplexing)

The time axis is divided in two, and fast alternate transmissions occur (e.g. WiFi)

RU = [E, MCS, fc, t0, Tt, Bc, Ga]

Radio Resources: Bi-directionality

Duplexing Technique	Advantages	Disadvantages
FDD	simple	duplexer needed to avoid transmitter-to-receiver interference
TDD	cheaper	synchronisation at link level receiver sensitivity (larger overall bit rate) synchronisation at network level

2. Assignment of Radio Resources

Radio Resource Assignment

Radio Resource Set

It is the set of RUs available to the users in a given area.

Radio Resource Set Capacity

It is the number of RUs that can be assigned to the users in a given area under some QoS constraints.

Hard Capacity: in some cases the maximum number of RUs available is known

Soft Capacity: in some other cases this number has no fixed maximum value

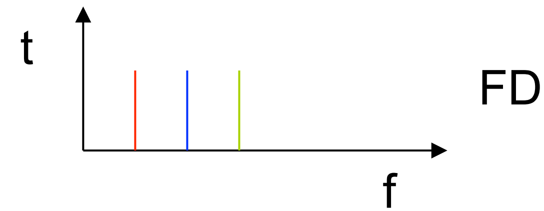
Radio Resource Assignment

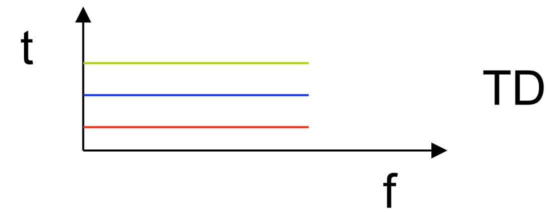
Radio Resources can be assigned to users *orthogonally* within a given area:

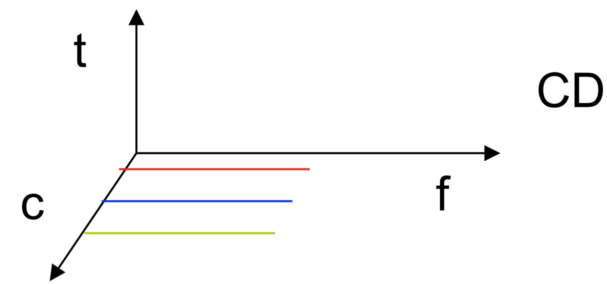
$$\text{Int}\,[\,x(t)\,y(t)\,] = 0$$

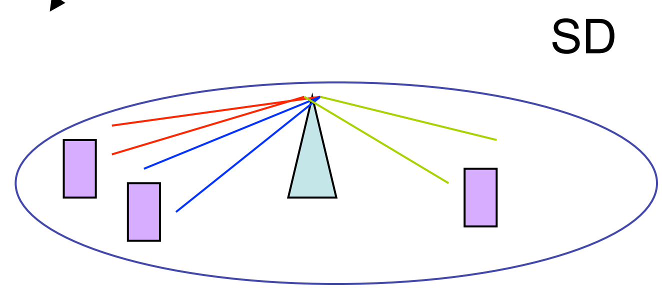
If they are orthogonal, users will not interfere.
Otherwise, *collision resolution* or *interference rejection* techniques must be used
(NOMA: Non Orthogonal Multiple Access).

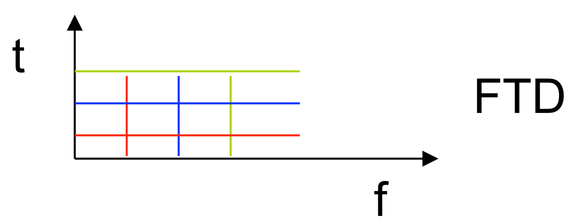
Ortogonality can be reached via Frequency (FD), Time (TD), Code (CD), Space Division (SD) or a mixture of them (e.g. FTD)



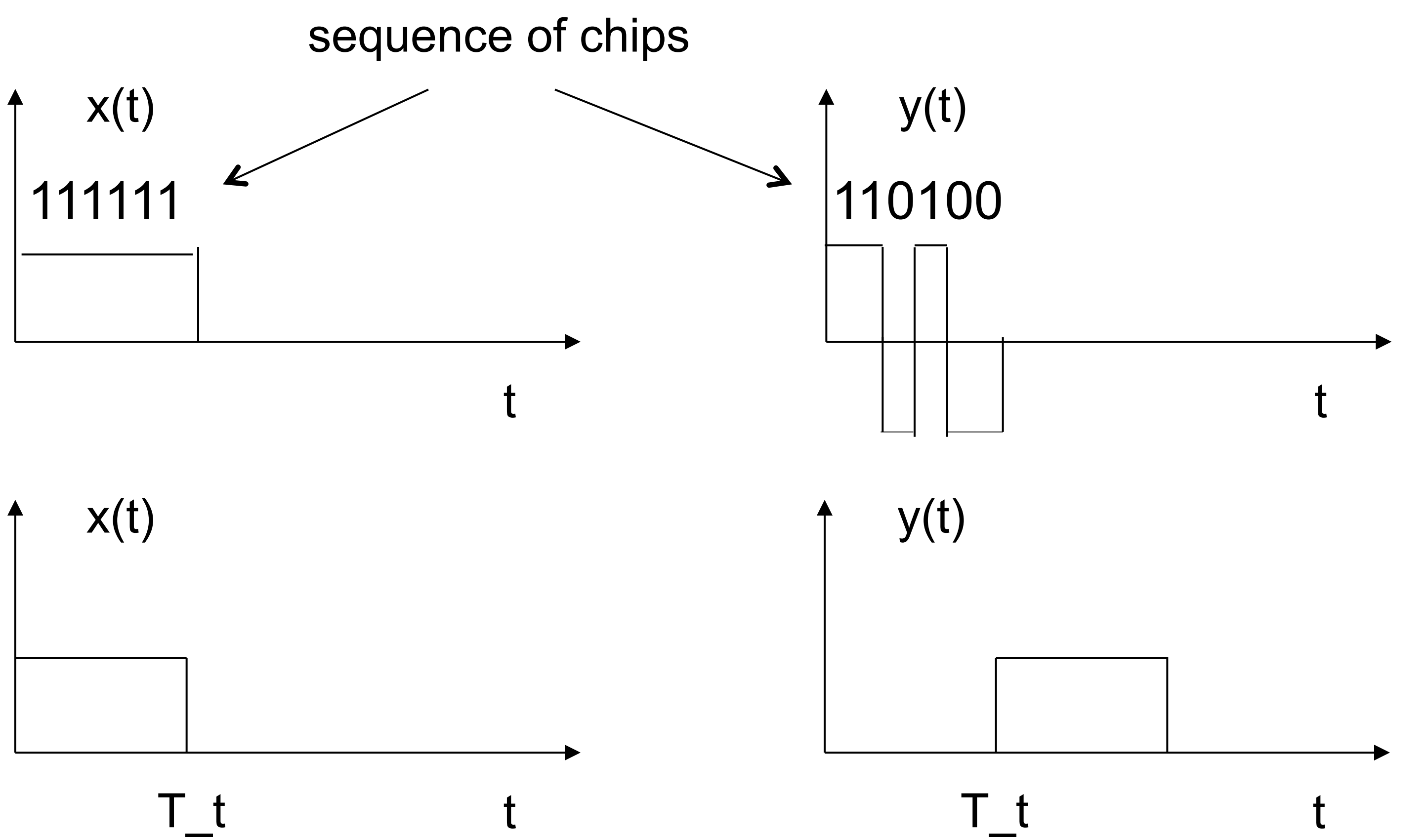








Radio Resource Assignment



CDMA

TDMA

$x(t) = X \cos(2 \pi f_1 t) \text{ rect } (t/T)$

$y(t) = Y \cos(2 \pi f_2 t) \text{ rect } (t/T)$

$f_1 \neq f_2$

FDMA (approx)

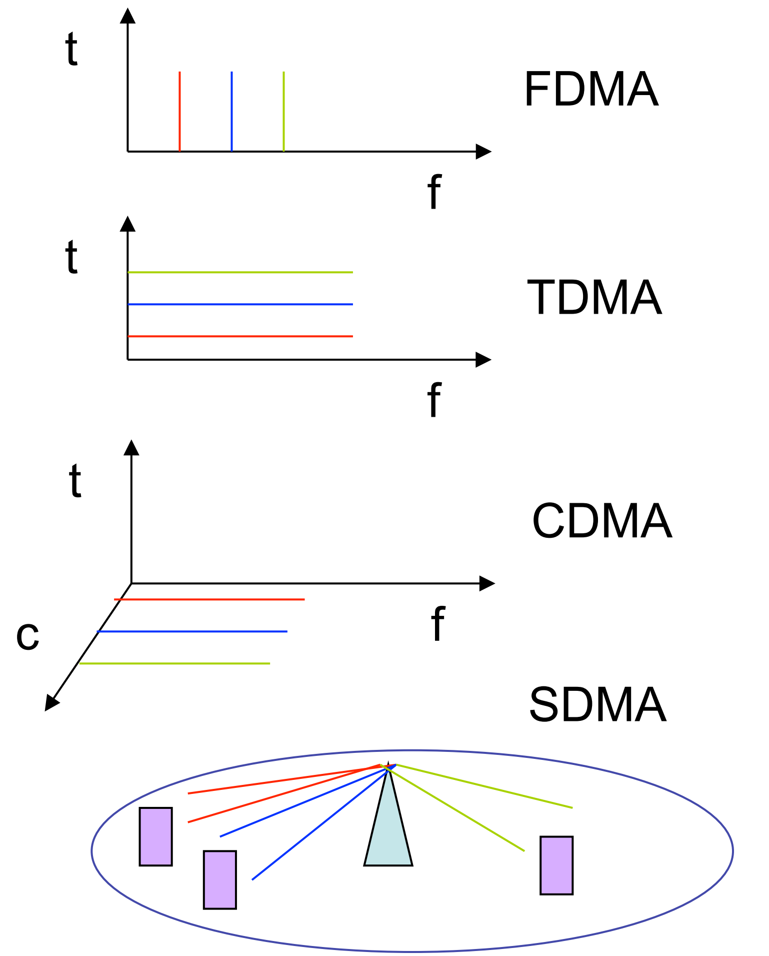
Radio Resource Assignment

RU = [E, MCS, fc, t0, Tt, Bc, Ga]

RU = [E, MCS, fc, t0, Tt, Bc, Ga]

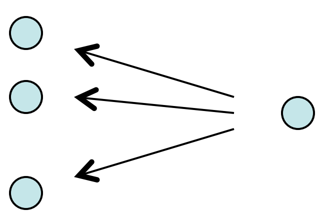
RU = [E, MCS, fc, t0, Tt, Bc, Ga]

RU = [E, MCS, fc, t0, Tt, Bc, Ga]

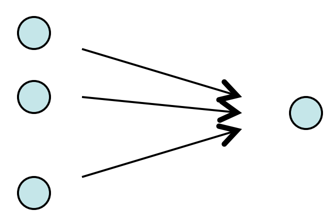


Radio Resource Assignment

MA Technique	Advantages	Disadvantages
FDMA	simple	# of receivers in MPtoP non linear effects in PtoMP
TDMA	cheaper in MPtoP slots for measurements	synchronisation receiver sensitivity
CDMA	inherent encryption time resolution	code orthogonality larger bandwidth
SDMA	protection against interference space is not limited resource	technological complexity



PtoMP



MPtoP

Radio Resource Assignment

(Centralised) Fixed RR Assignment

A centralised network entity assigns RUs to nodes based on pre-defined schemes

(Centralised) Dynamic RR Assignment

A centralised network entity assigns RUs to nodes based on dynamic schemes
[scheduling]

(Distributed) Controlled RR Assignment

Nodes self-assign RUs based on concerted policies

(Distributed) Random RR Assignment

Nodes self-assign RUs without concerted policies

3. Area Coverage Networks

Area Coverage: Hot Spot

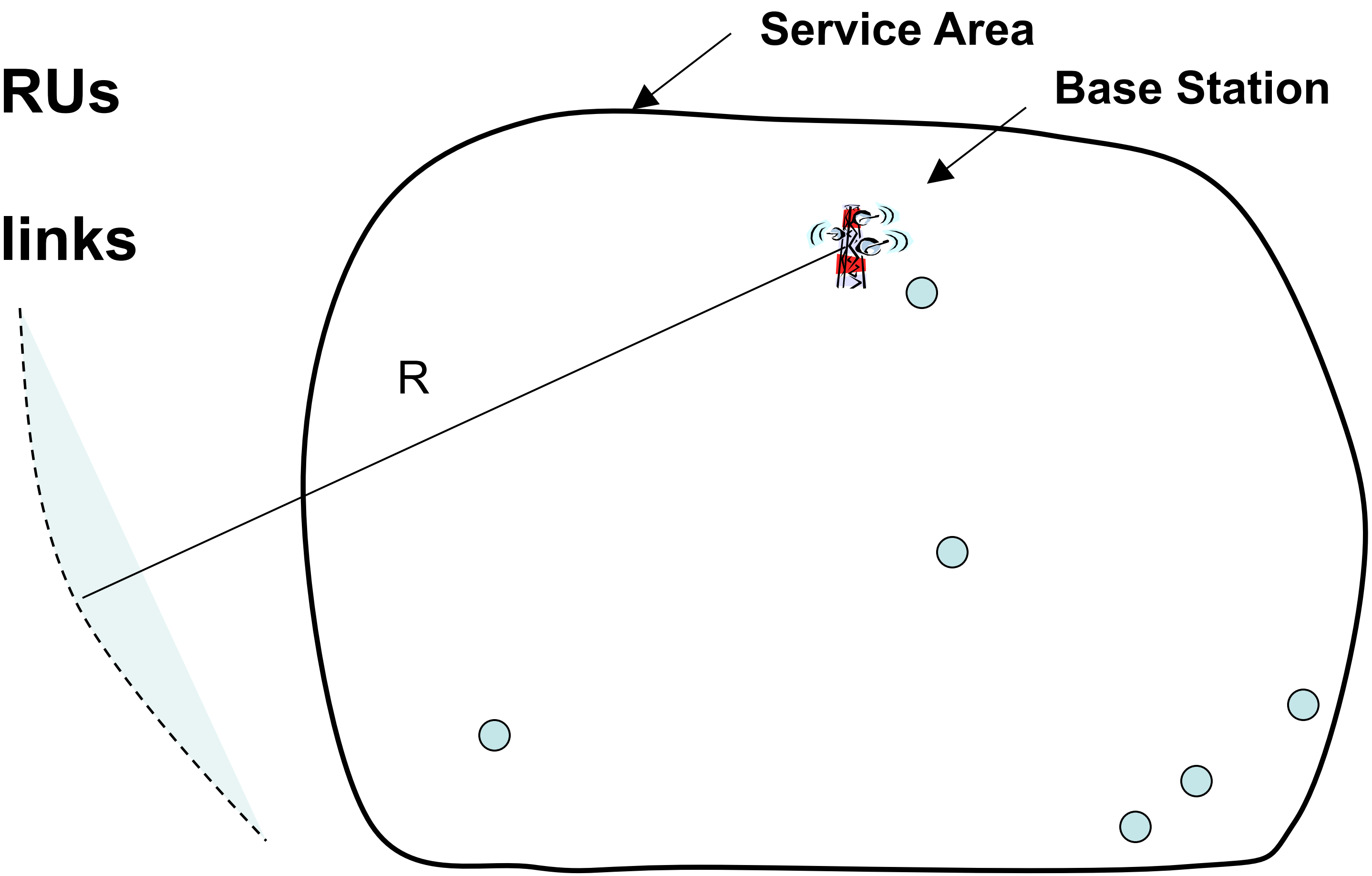
N RUs

L links

Ex.:

N = 12

L = 6

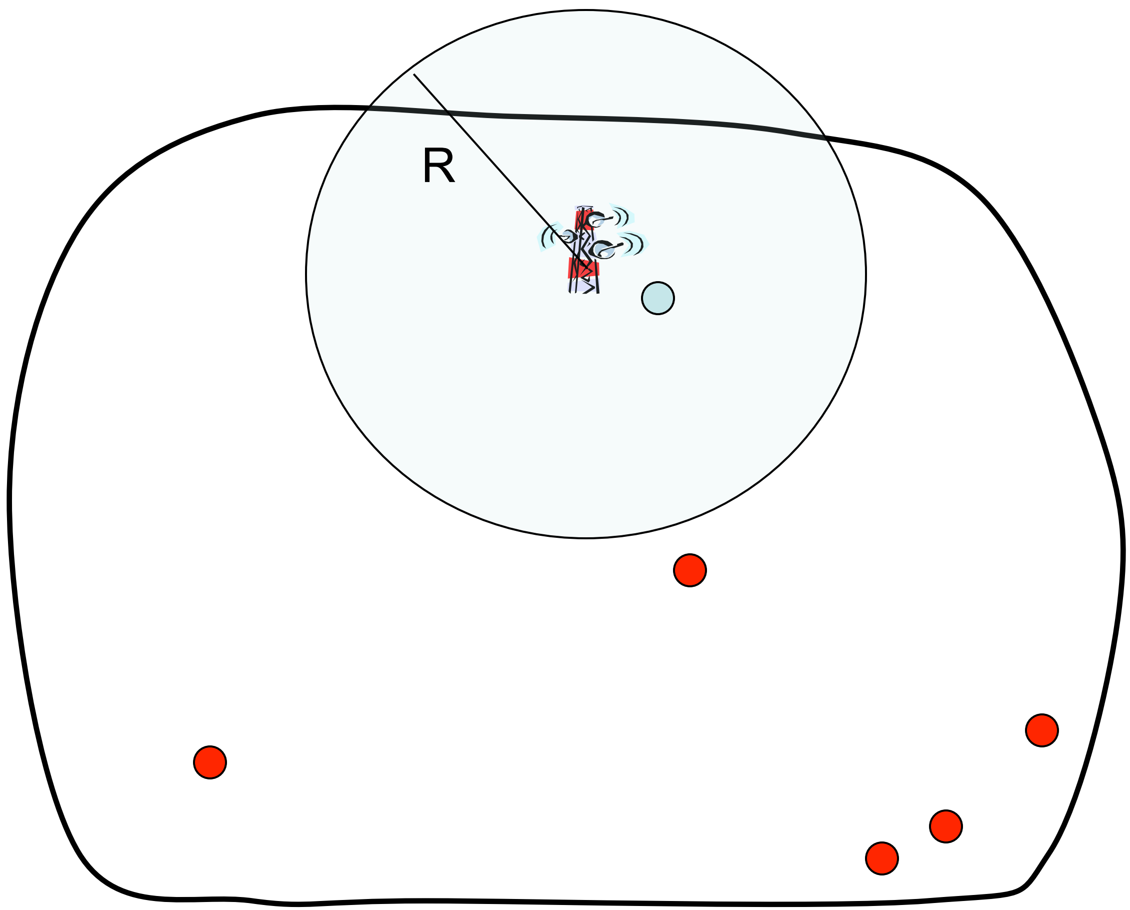


Assumptions: N > L R sufficiently large

Area Coverage: Hot Spot

N RUs

L links



Ex.:

N = 12

L = 6

Assumptions: N > L R not sufficiently large

Area Coverage: Cells

Ex.:

N RUs

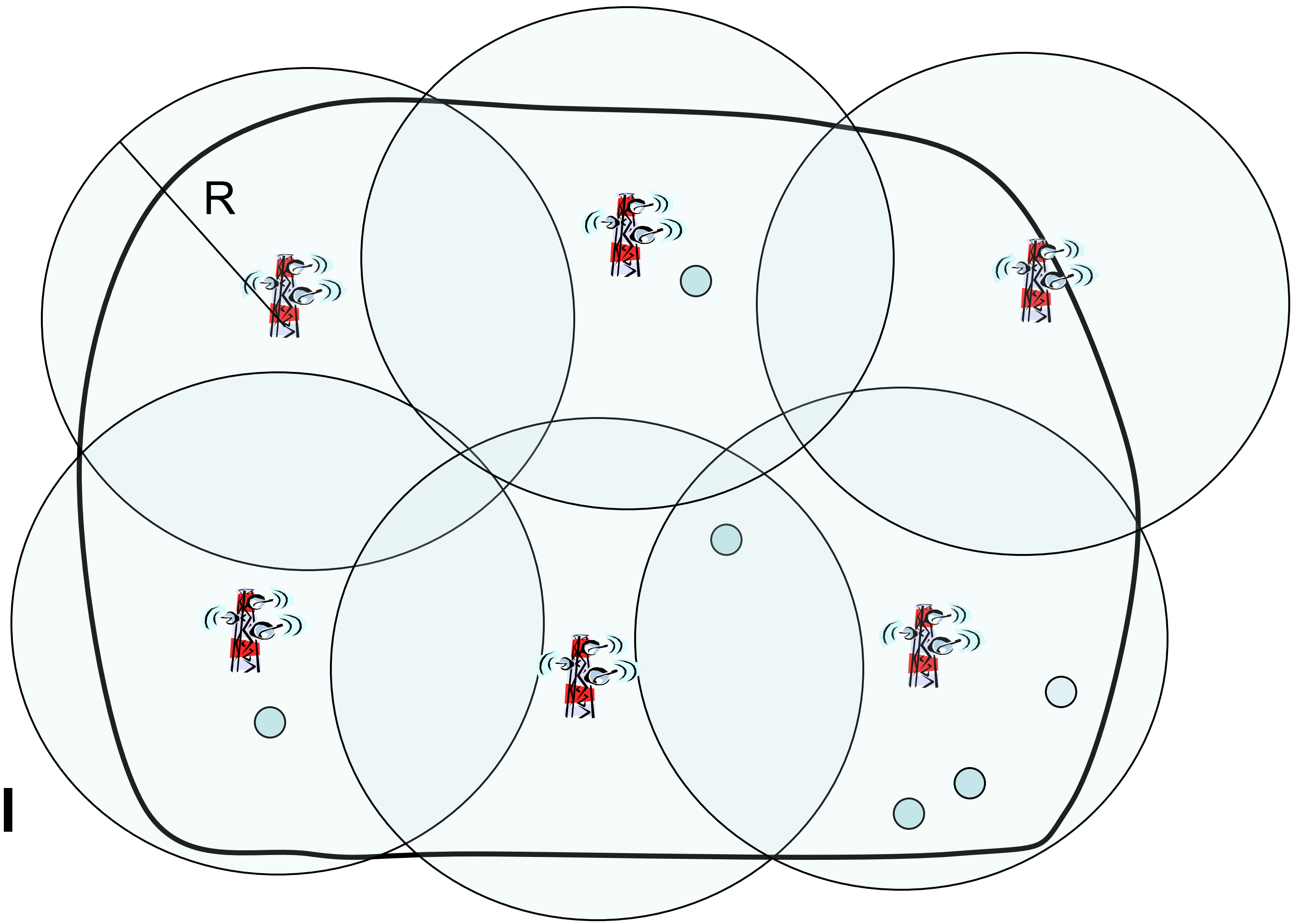
N = 12

L links

L = 6

Z cells

Z = 6



n RUs/cell

n = N / Z

n = 2

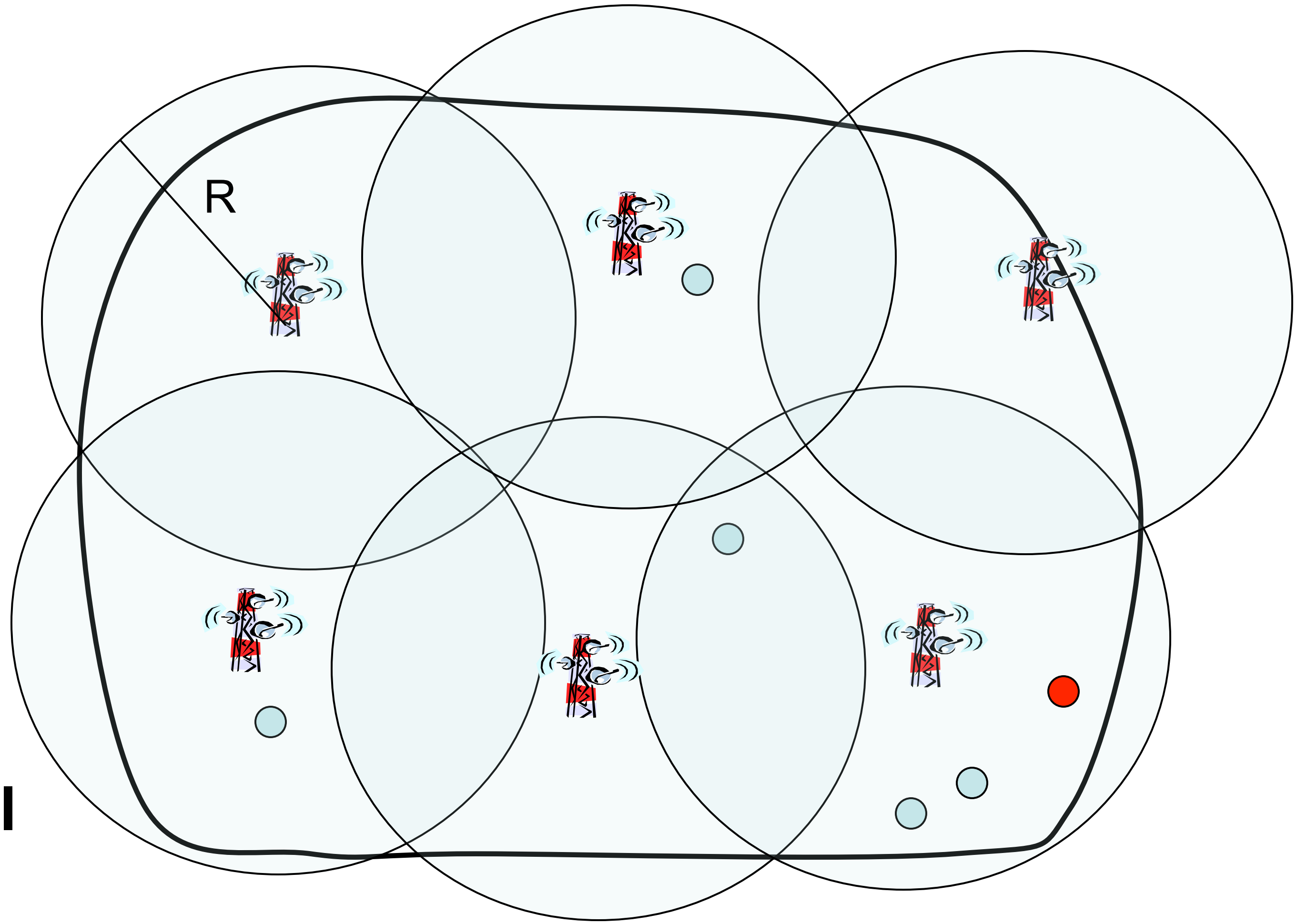
Area Coverage: Cells

Ex.:

N RUs — N = 12

L links — L = 6

Z cells — Z = 6

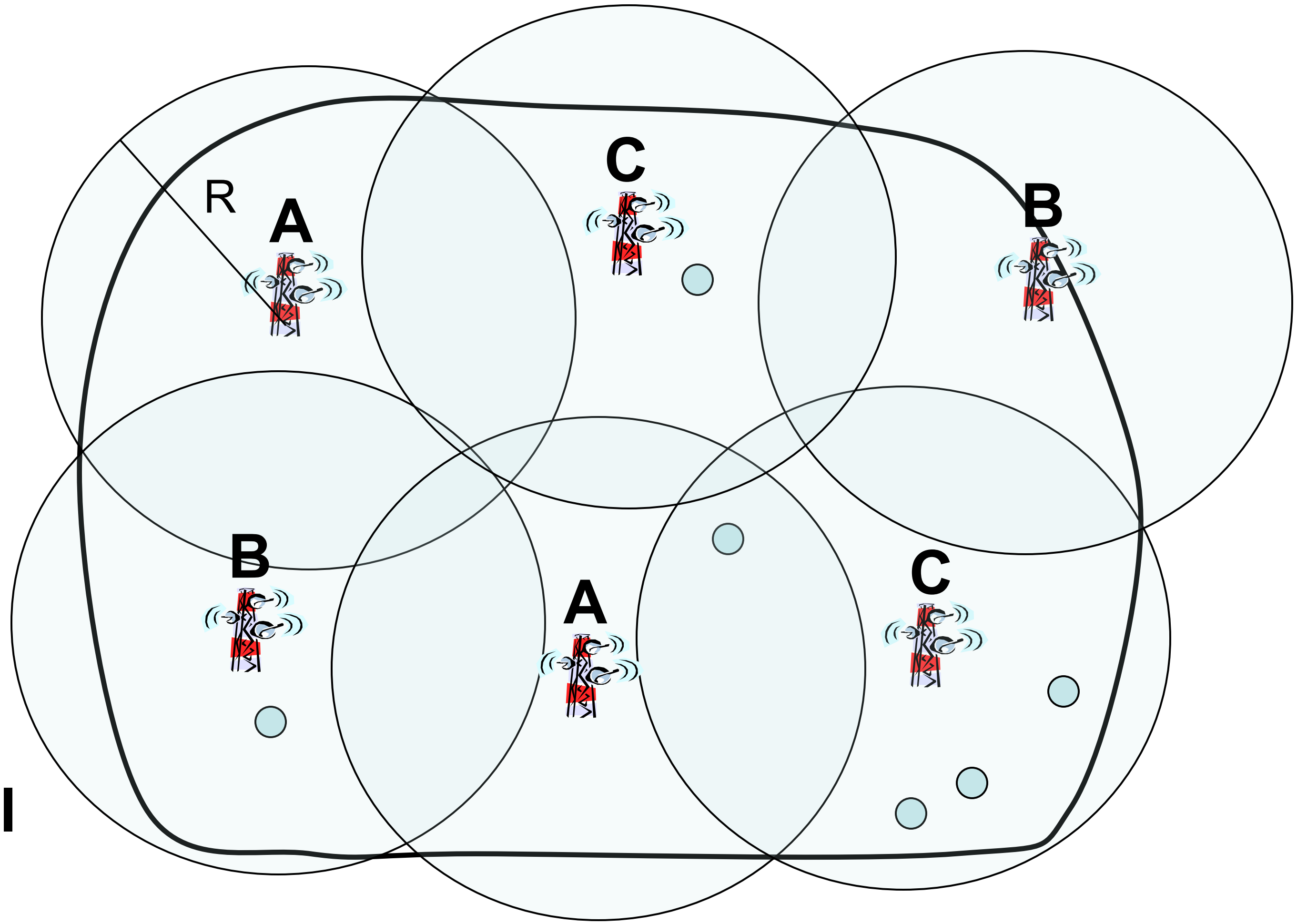


n RUs/cell — n = 2

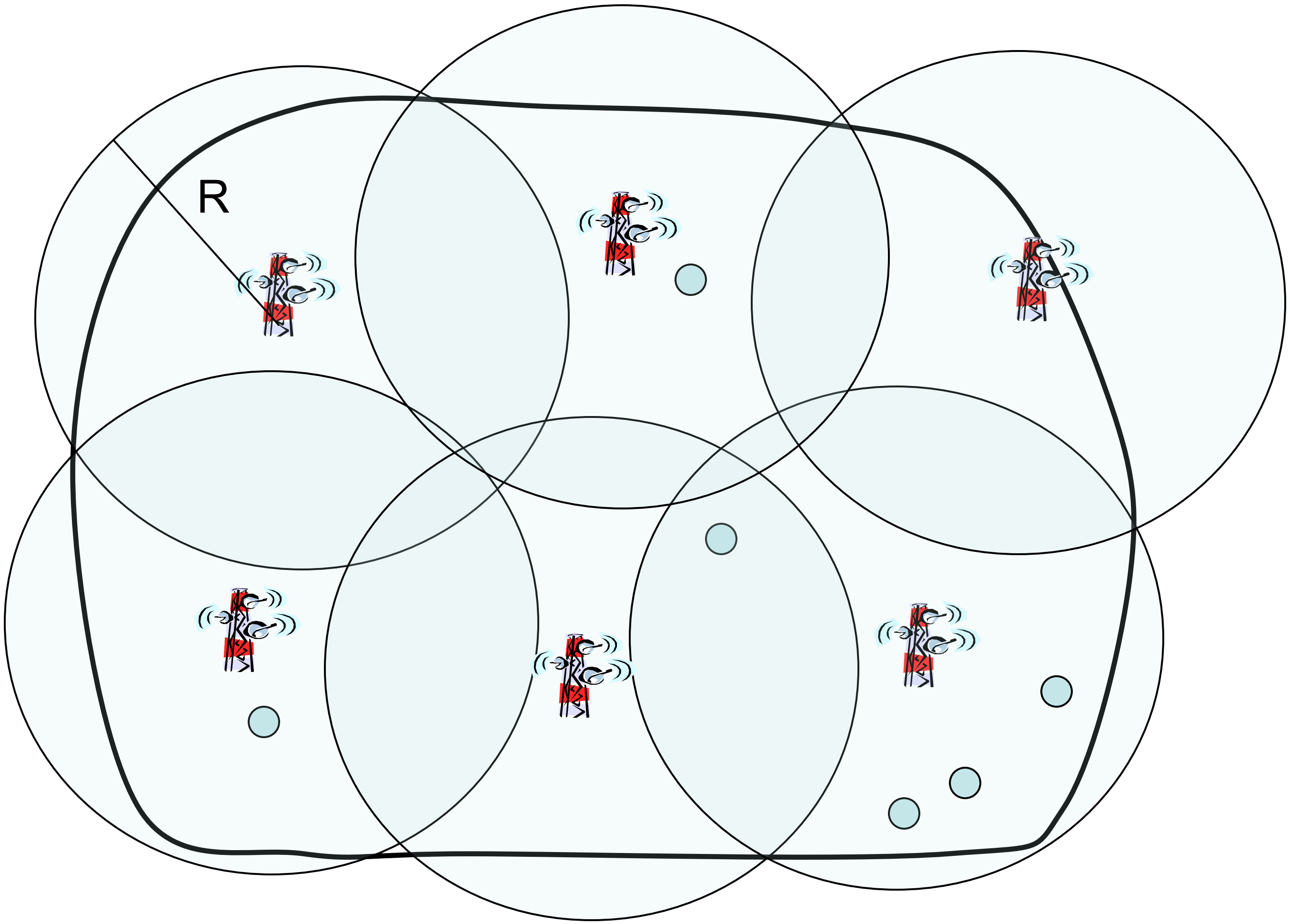
Splitting resources in separate pools is bad!

Area Coverage: Reuse

		Ex.:
N	RUs	N = 12
L	links	L = 6
Z	cells	Z = 6
K	cells / cluster	K = 3
n	RUs/cell	
n = N / K		n = 4

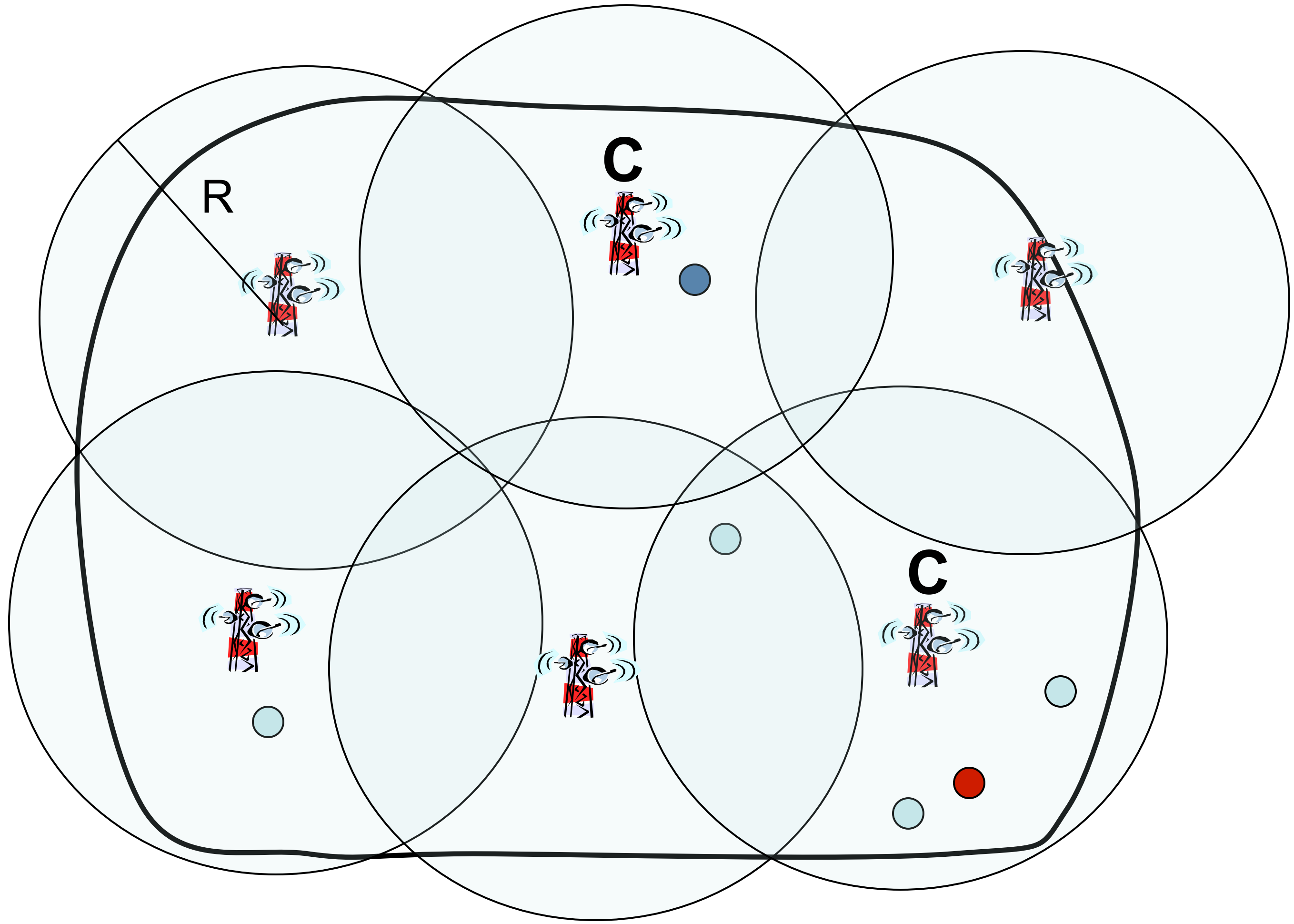


Area Coverage: Reuse



Reuse improves Capacity …

Area Coverage: Reuse

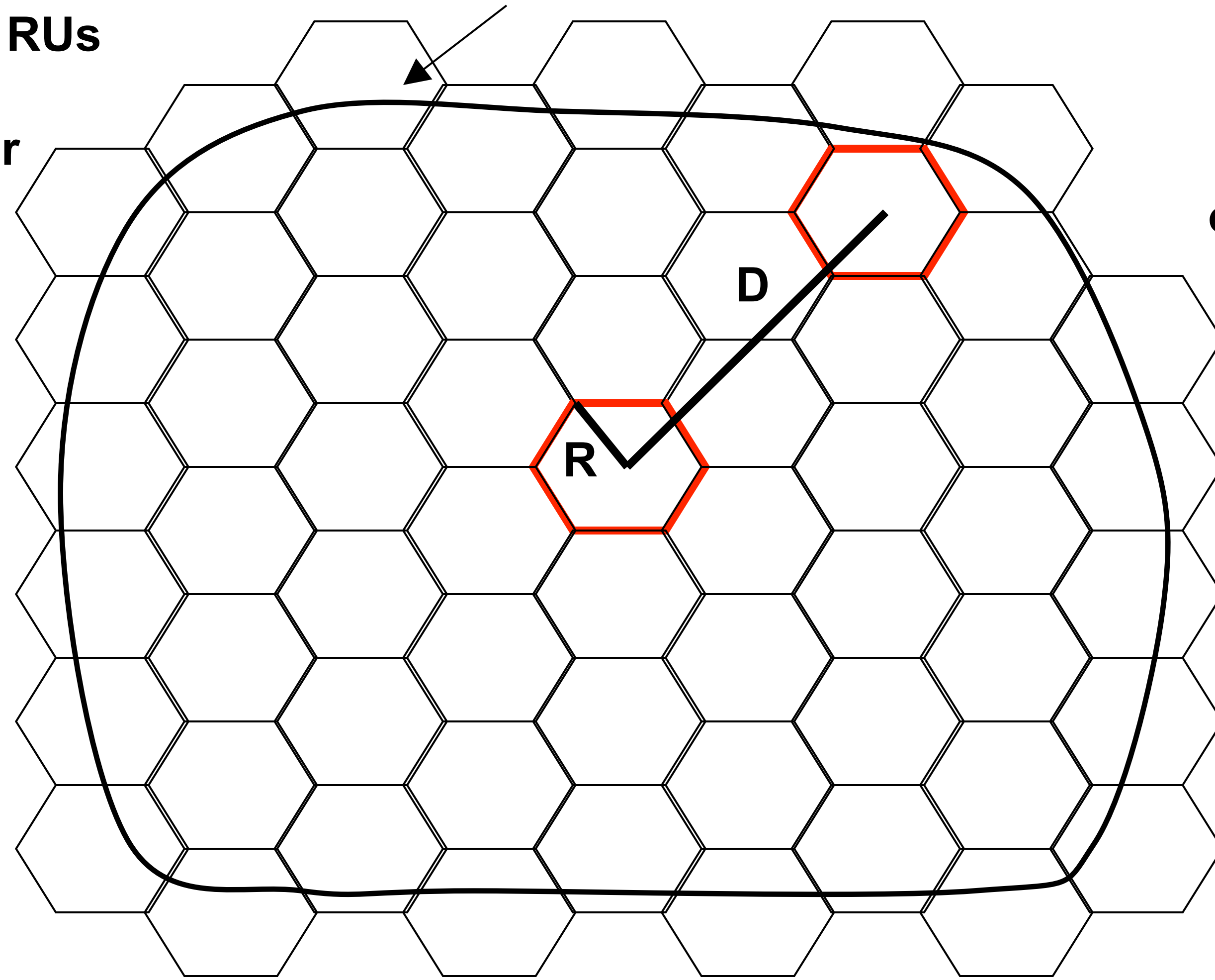


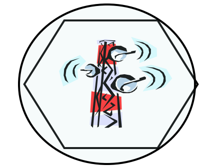
…at the cost of inter-cell interference!

4. Reuse

Reuse

Service Area (Z = 60 cells)





One base per cell with omnidirectional antenna system

FDD

N orthogonal RUs

K cells/cluster

$n = N / K$ RUs/cell

$A = 3^{3/2} R^2 / 2$ cell area

$Q = D / R$ Reuse Factor

Z cells

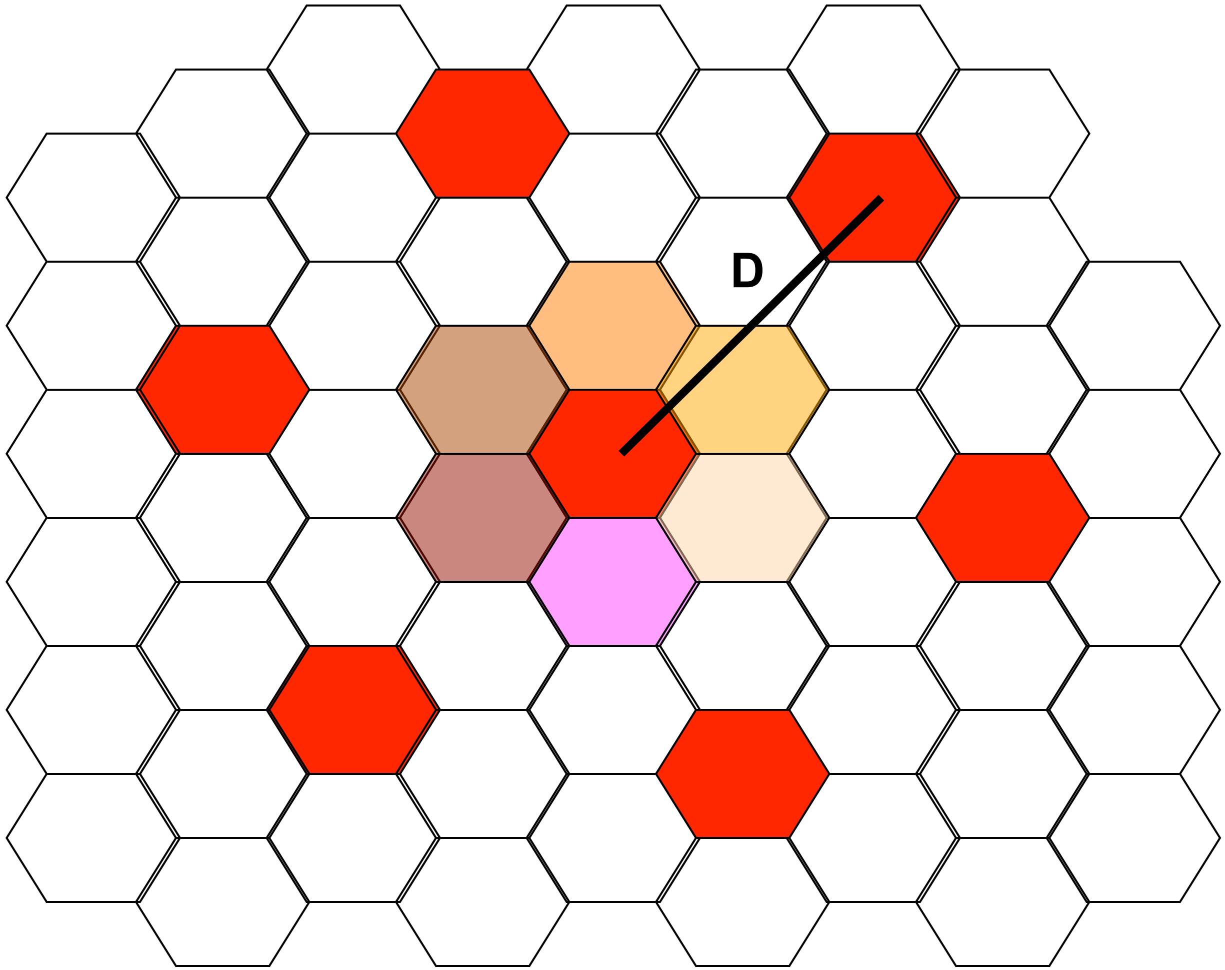
RR Set Capacity: $Z n = Z N / K$

Carrier-to-Interference Ratio (CIR or SIR): C / I

Reuse

K = 7

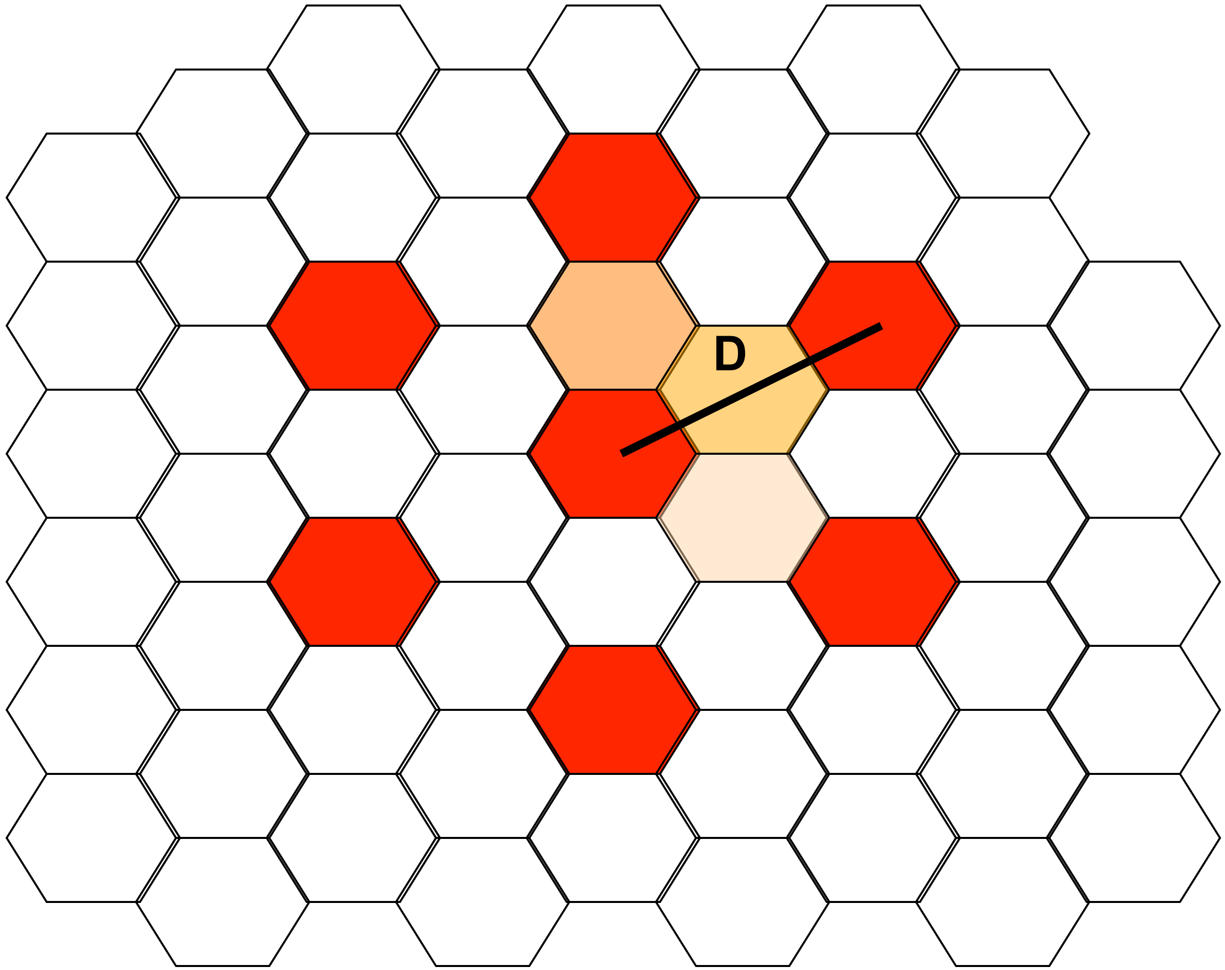
Six first – tier interferers



Reuse

K = 4

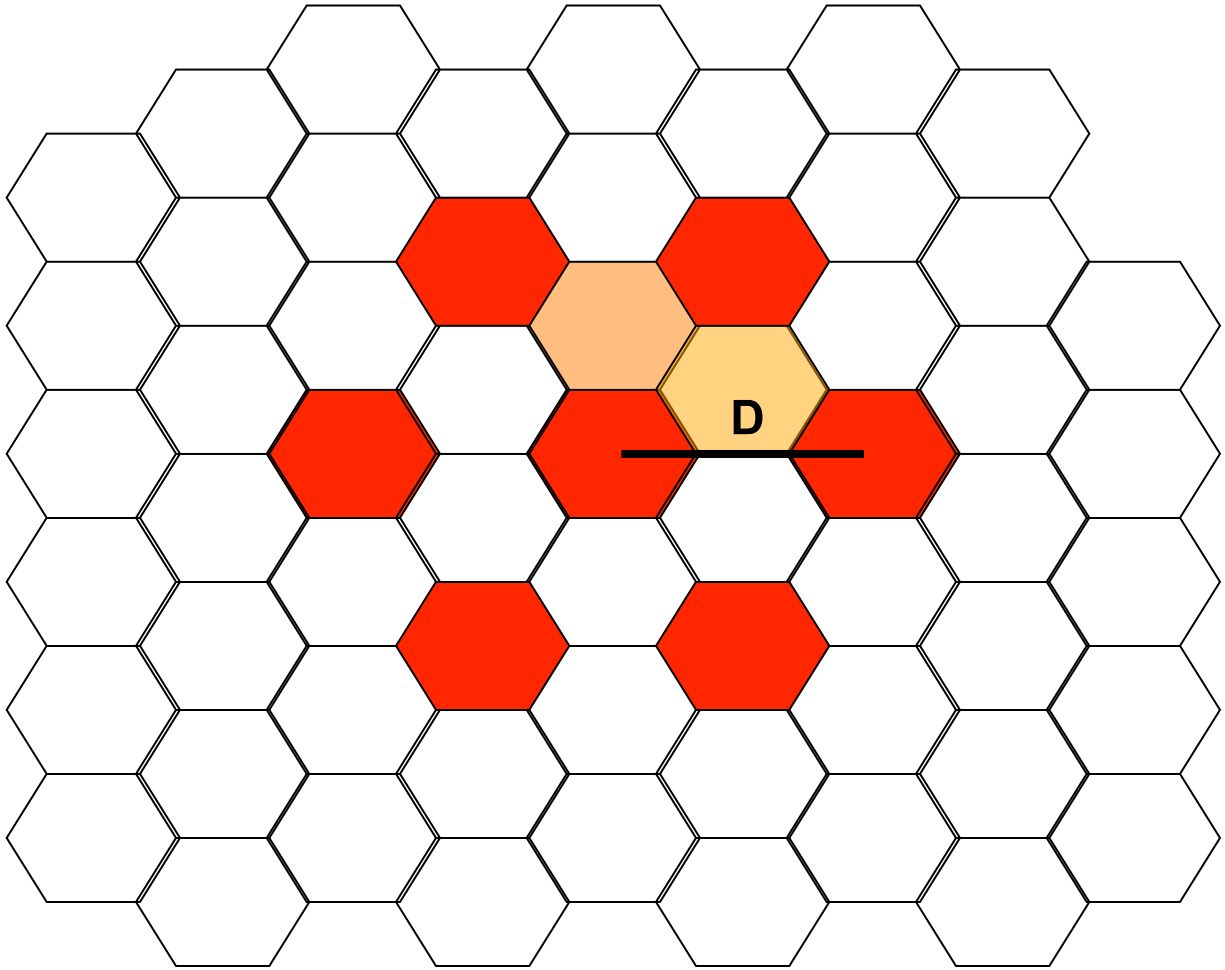
Six first – tier interferers



Reuse

K = 3

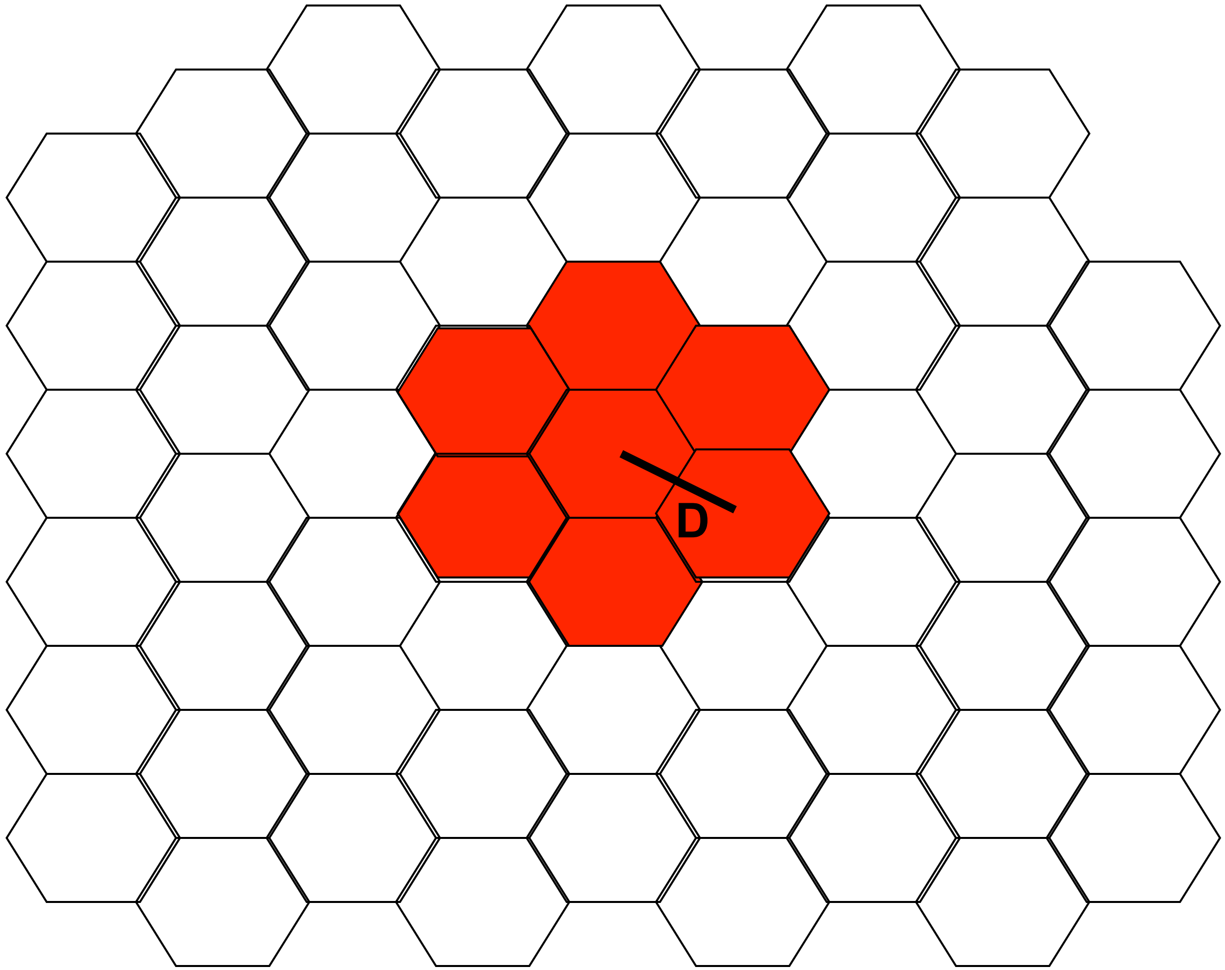
Six first – tier interferers



Reuse

K = 1

Six first – tier interferers



Reuse

$K = i^2 + j^2 + i\,j$ $\qquad$ $i = 0,1,2,3,4,\ldots \quad j = 0,1,2,3,4,\ldots$

i	j	K	
1	0	1	(full reuse)
1	1	3	
2	0	4	
2	1	7	
3	0	9	
2	2	12	
…			

$D = R\,(3\,K)^{1/2}$ $\qquad$ $n = N / K$ is a (rough) measure of the cell capacity

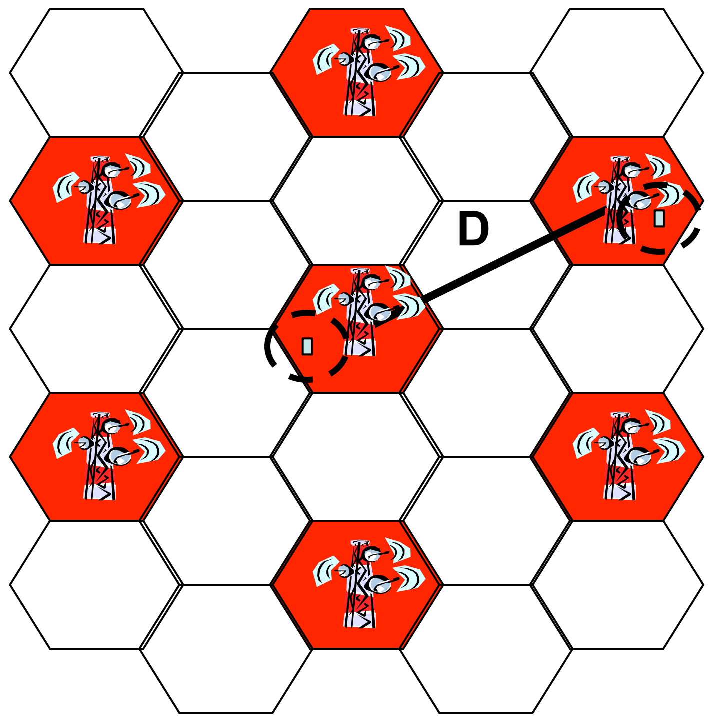
$Q = (3\,K)^{1/2}$

Increasing K, D increases, but n decreases
(less interference, at the expense of a smaller capacity)

Reuse: Deterministic Conditions – Omni Antennas

$C = k\, d_u^{-\beta}$
$I = Sum_j\, k\, d_j^{-\beta}$

FDD



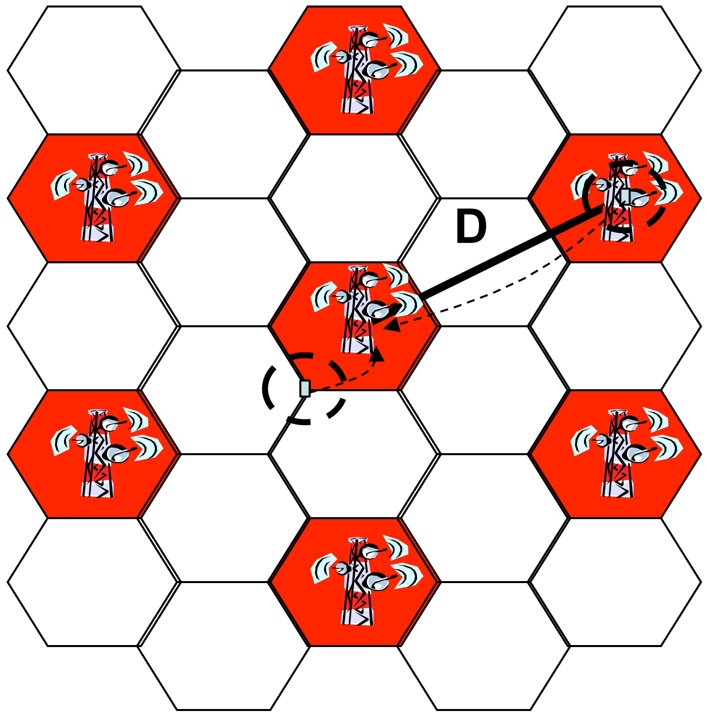
$C / I = k\, d_u^{-\beta} / Sum_j\, k\, d_j^{-\beta} = d_u^{-\beta} / Sum_j\, d_j^{-\beta}$

Reuse: Deterministic Conditions – Omni Antennas

$C = k\,R^{-\beta}$ (worst situation)
$I = Nint\,k\,D^{-\beta}$ (average situation)

FDD

uplink



$C / I = Q^{\beta} / Nint = (3\,K)^{\beta/2} / Nint$

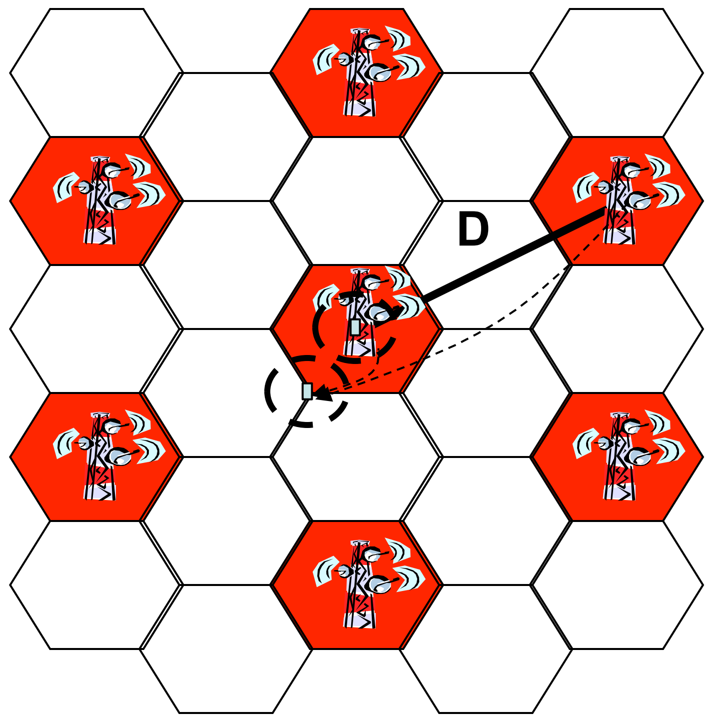
Reuse: Deterministic Conditions – Omni Antennas

$C = k\,R^{-\beta}$ (worst situation)

$I = Nint\;k\,D^{-\beta}$ (average situation)

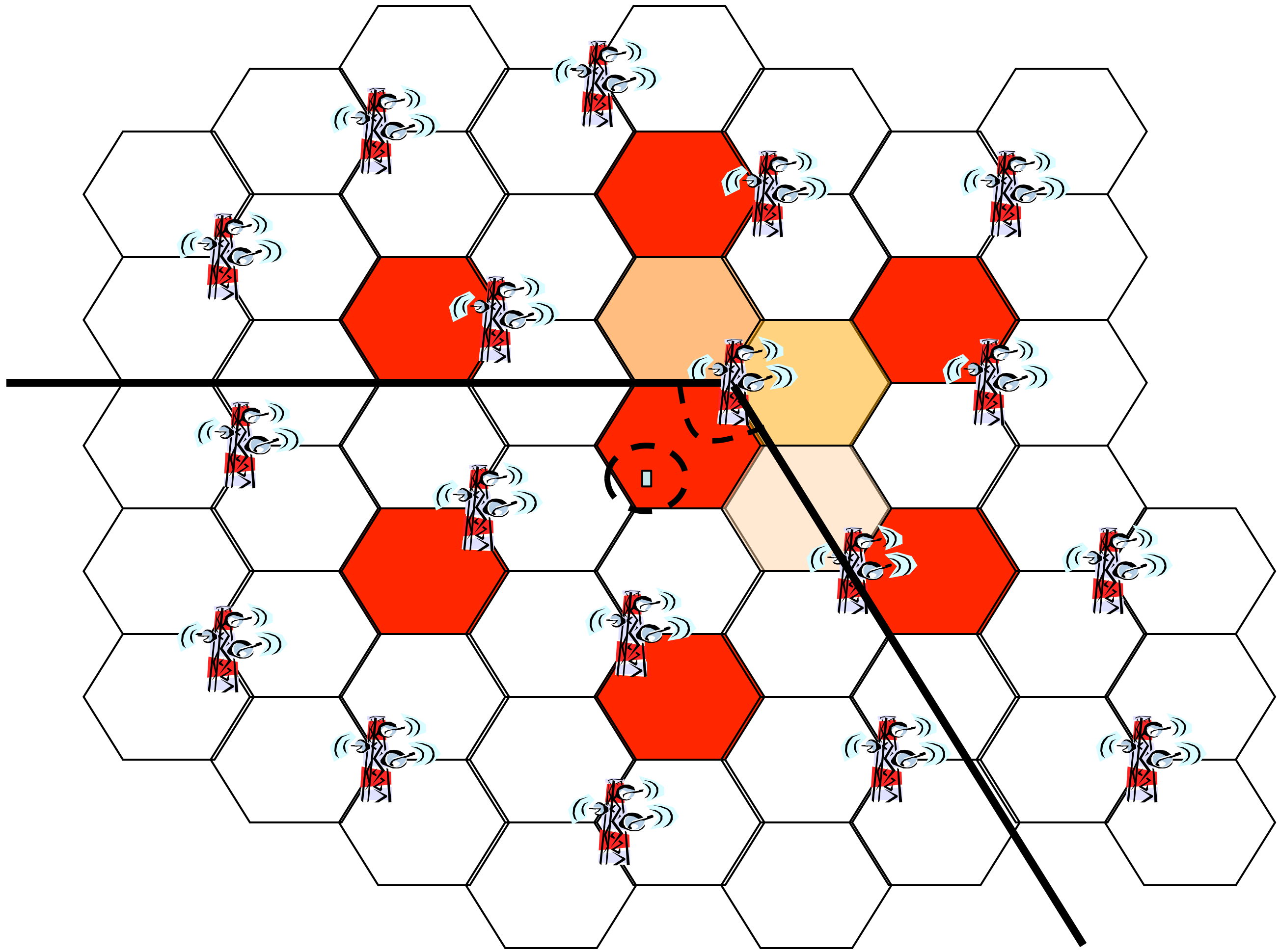
FDD

downlink



$C / I = Q^{\beta} / Nint = (3\,K)^{\beta/2} / Nint$

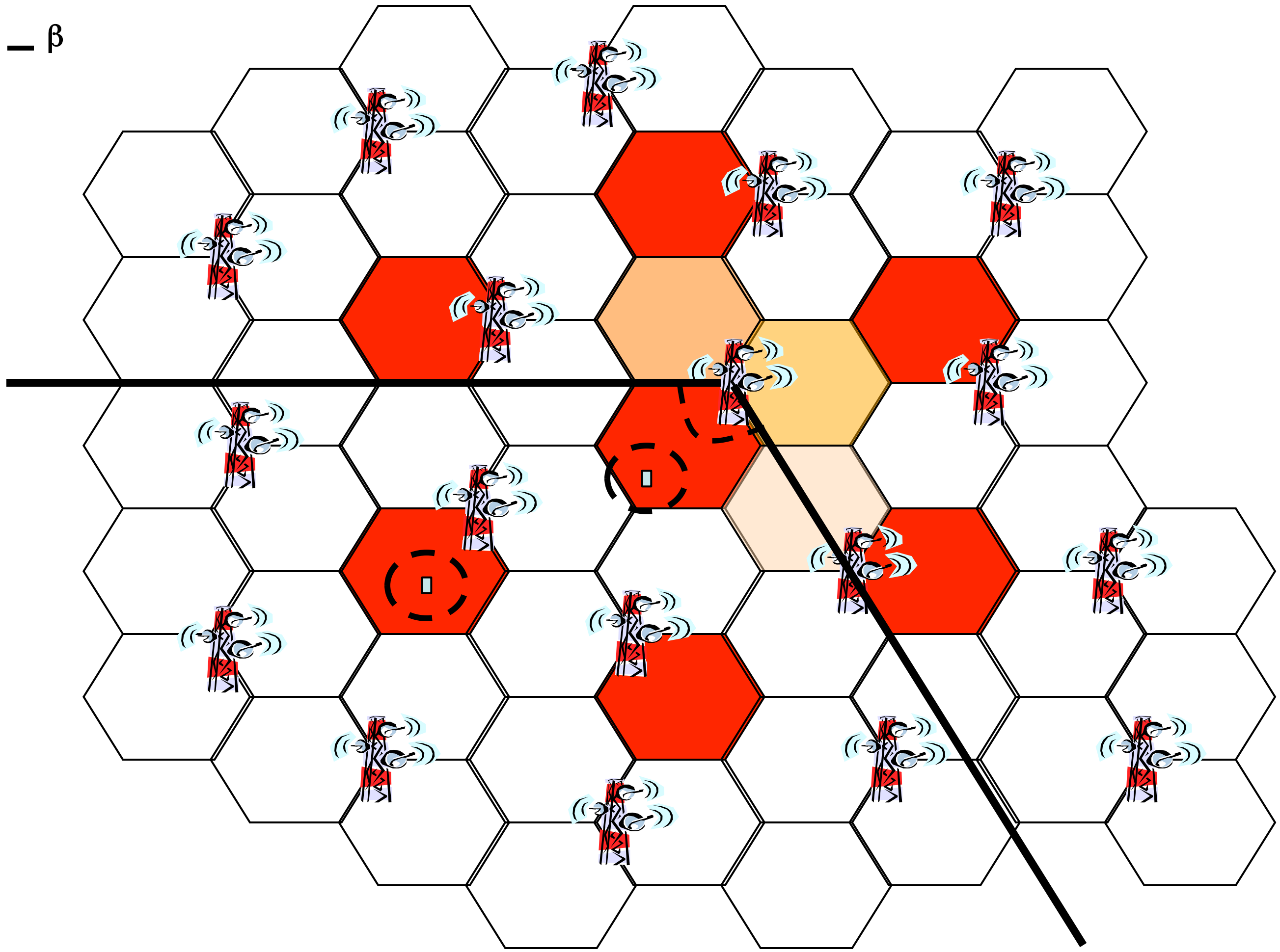
Reuse: Deterministic Conditions – Tri-Sect Antennas



Reuse: Deterministic Conditions – Tri-Sect Antennas

$C = k\, d_u^{-\beta}$
$I = \mathrm{Sum}_j\, k\, d_j^{-\beta}$

FDD



C / I = ?

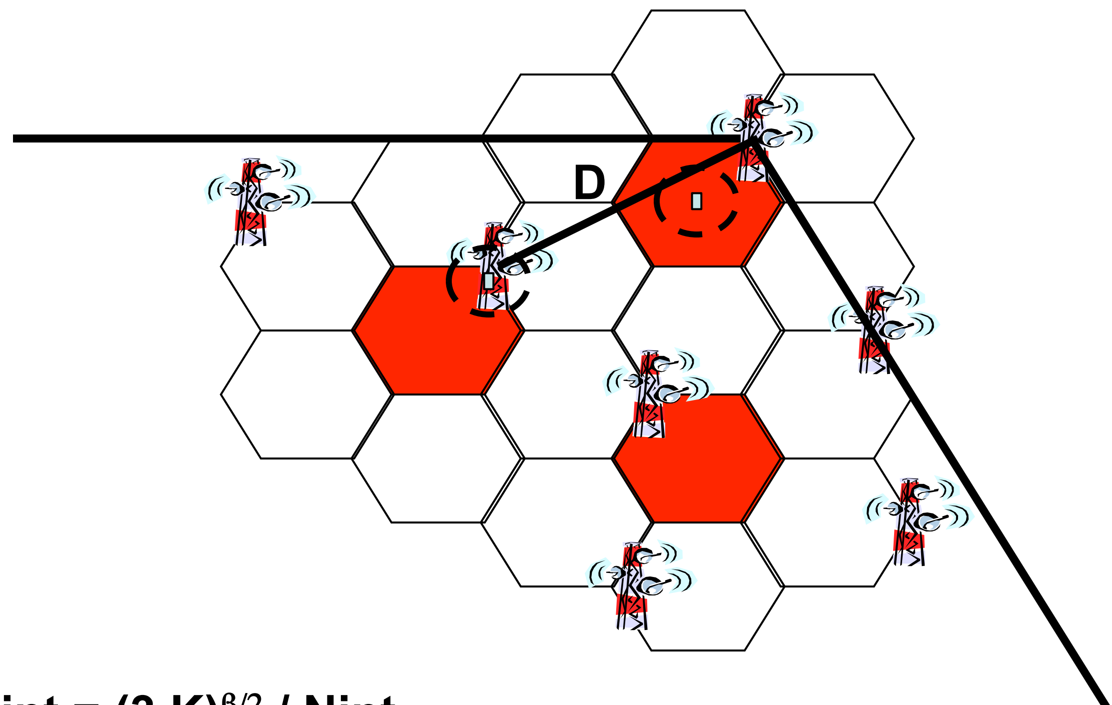
Reuse: Deterministic Conditions – Tri-Sect Antennas

$C = k\ R^{-\beta}$ (average situation)

$I = Nint\ k\ D^{-\beta}$ (worst situation)

FDD

uplink



$C / I = Q^{\beta} / Nint = (3\ K)^{\beta/2} / Nint$

Reuse

$C / I = Q^{\beta} / Nint = (3\ K)^{\beta/2} / Nint$

Nint = 6 (first tier) with omnidirectional antennas at the base stations
Nint = 2 (first tier) with three-sectorial antennas at the base stations

Reuse: How to Maximize Capacity?

N orthogonal RUs

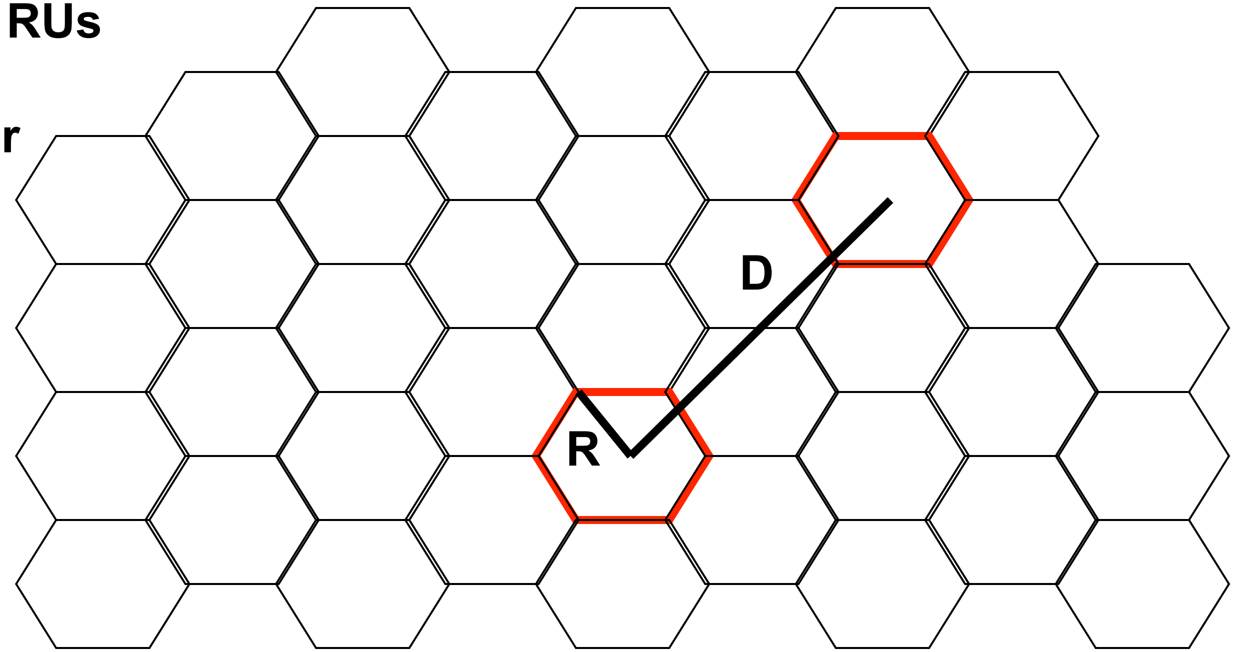
K cells/cluster

n = N / K
RUs/cell

$A = 3^{3/2} R^2 / 2$
cell area

Q = D / R
Reuse Factor

Z cells



RR Set Capacity: Z n = Z N / K (proportional to Z)

$C / I = Q^{\beta} / Nint = (3 K)^{\beta/2} / Nint$ (independent on Z)

Make cells as small as possible

Carrier-to-Interference Ratio scales!

Reuse: Exercise

Compute the C / I under deterministic conditions with propagation exponent equal to 4, for cluster size equal to 7, 4, 3 with omnidirectional and tri-sectorial antennas. Repeat computation for propagation exponent equal to 3.

Reuse: Exercise

Compute the C / I under deterministic conditions with propagation exponent equal to 4, for cluster size equal to 7, 4, 3 with omnidirectional and tri-sectorial antennas. Repeat computation for propagation exponent equal to 3.

$C / I = (3K)^{\beta/2} / N_{int}$

	Omnidirectional antennas	Tri-sectorial antennas
$\beta = 4$		
K = 7	**18.7 dB**	**23.4 dB**
K = 4	**13,8 dB**	**18.6 dB**
K = 3	**11.3 dB**	**16.1 dB**
$\beta = 3$		
K = 7	**12.1 dB**	**16.9 dB**
K = 4	**8.4 dB**	**13.2 dB**
K = 3	**6.5 dB**	**11.3 dB**

Reuse: Exercise

Compute the C / I under deterministic conditions with propagation exponent equal to 4, for cluster size equal to 7, 4, 3 with omnidirectional and tri-sectorial antennas. Repeat computation for propagation exponent equal to 3.

$C / I = (3K)^{\beta/2} / Nint$

	Omnidirectional antennas	Tri-sectorial antennas
$\beta = 4$		
K = 7	18.7 dB	23.4 dB
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K = 3	11.3 dB	16.1 dB
$\beta = 3$		
K = 7	12.1 dB	16.9 dB
K = 4	8.4 dB	13.2 dB
K = 3	6.5 dB	11.3 dB

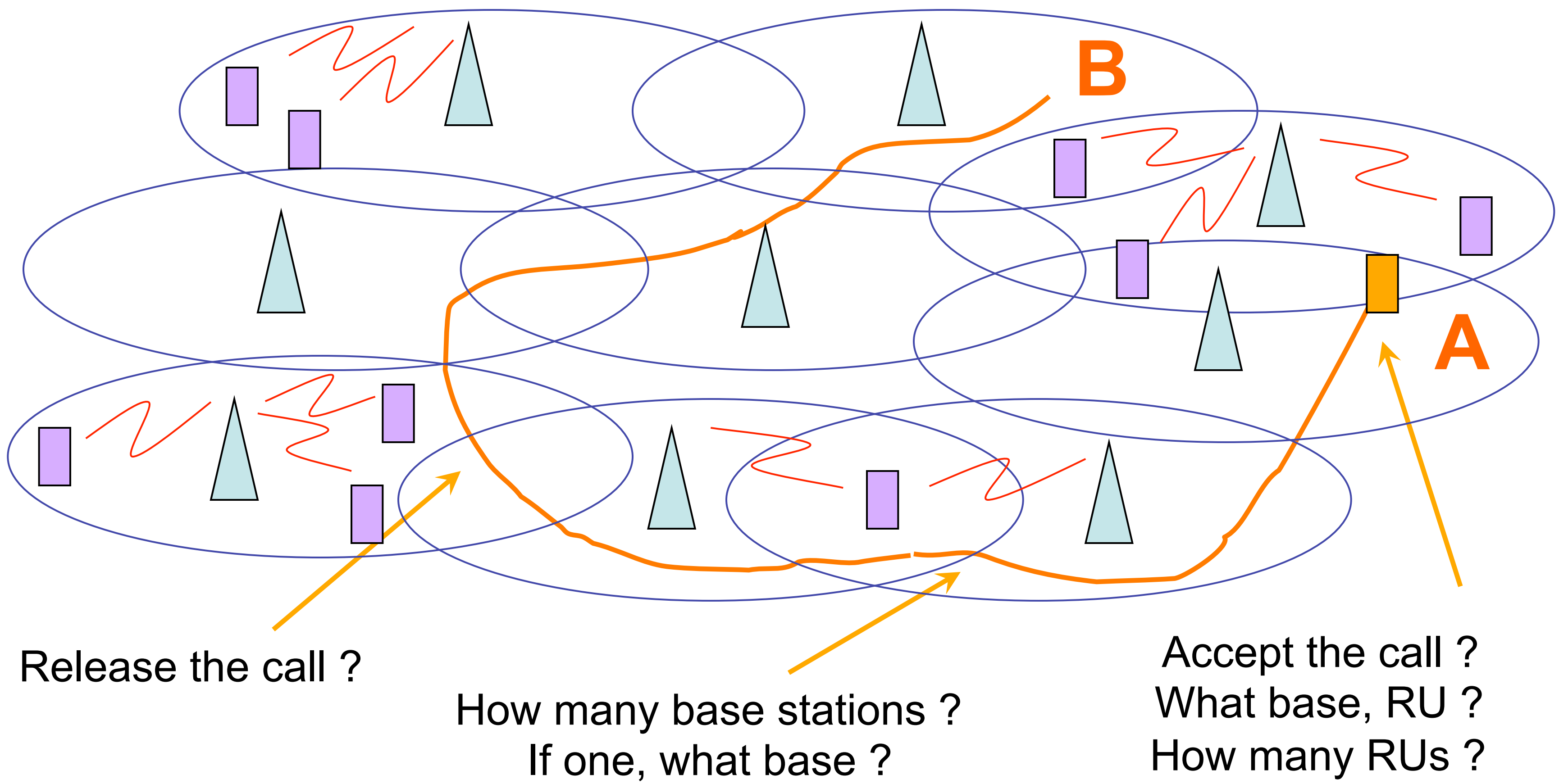
5. Radio Resource Management

Radio Resource Management

RRM techniques aim at optimising the use of radio resources while fulfilling the quality requirements of the largest possible number of users

Radio Resource Management

Decisions to be taken by the RRM entities (C.S. Services)



Radio Resource Management

Decisions to be taken by the RRM entities (C.S. Services)

At call set up:

Admission control	(whether to accept a new call)
Initial base station assignment	(what base)
Initial channel assignment	(what RU)
Initial bandwidth assignment	(how many RUs)

During the call:

Power control	(what power)
Base re-assignment	(what base)
Re-assignment of the number of bases	(how many bases)
Channel re-assignment	(what RU)
Bandwidth re-assignment	(how many RUs)
Call release	(whether to release a call)

Radio Resource Management

Decisions to be taken by the RRM entities (P.S. Services)

At Packet Data Transfer (PDT) set up:

Admission control	(whether to accept a new PDT)
Initial base station assignment	(what base)
Initial channel assignment	(what RU)
Initial bandwidth assignment	(how many RUs)

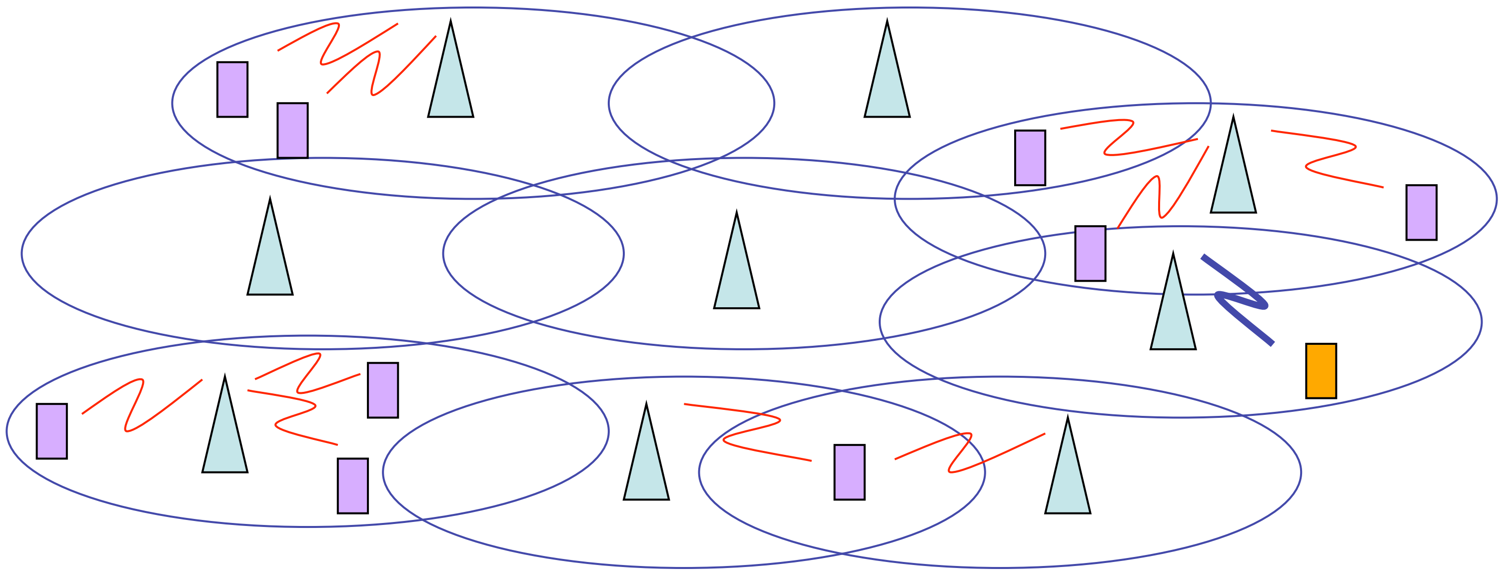
During the PDT:

Power control	(what power)
Base re-assignment	(what base)
Re-assignment of the number of bases	(how many bases)
Channel re-assignment	(what RU)
Bandwidth re-assignment	(how many RUs)
Call release	(whether to release a PDT)

Radio Resource Management

Admission Control — **The process of determining whether a service request can be admitted to the system**

Radio Resource Management: Admission Control



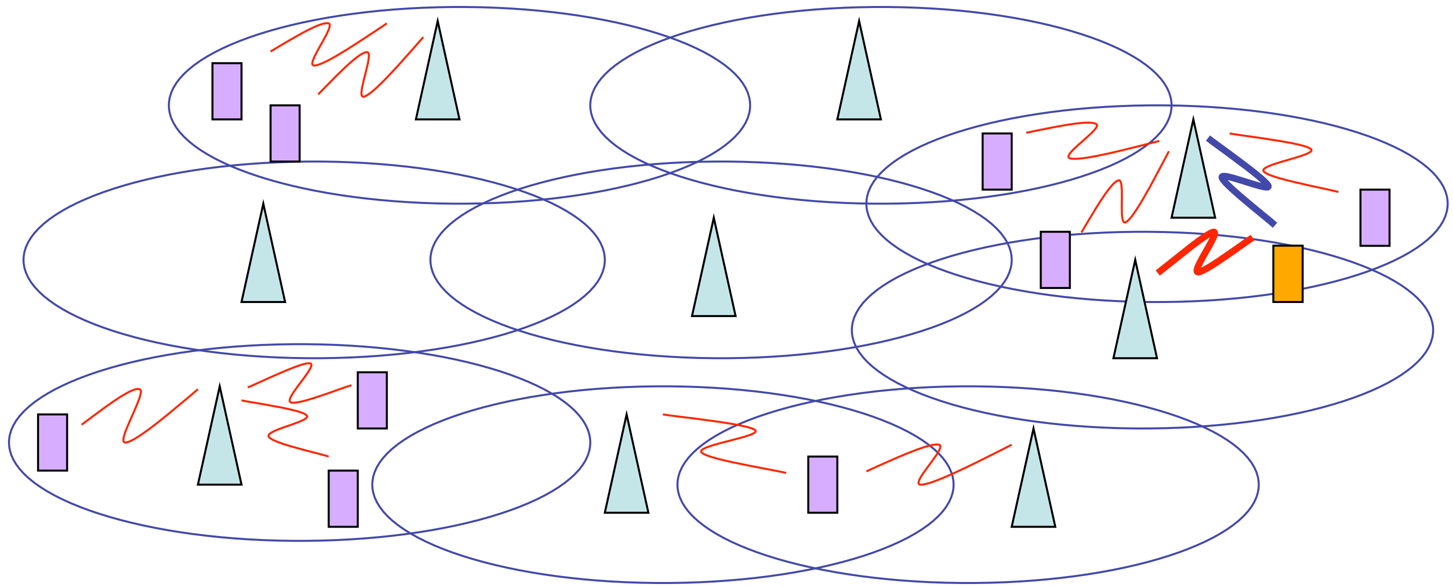
The call could be rejected for reasons related to capacity, or interference levels

Networks planned with reference to worst-case:
Admission Control is normally absent (e.g. GSM)

Radio Resource Management

Admission Control	**The process of determining whether a service request can be admitted to the system**
Directed Retry	**The process of re-directing a new user toward a base station different from the one providing the best link budget**

Radio Resource Management: Directed Retry



If one base cannot provide service, the call request is re-directed toward a different base (if within range).

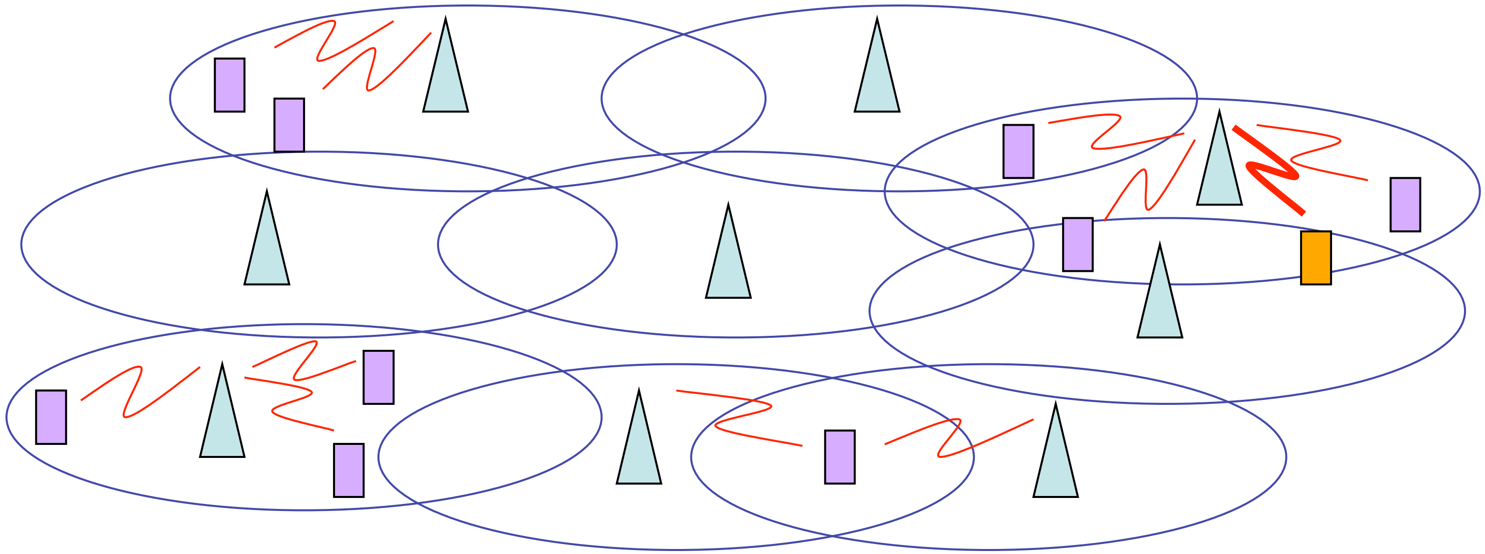
Networks planned with reference to worst-case:

Directed Retry is normally present (e.g. GSM)

Radio Resource Management

Admission Control	**The process of determining whether a service request can be admitted to the system**
Directed Retry	**The process of re-directing a new user toward a base station different from the one providing best link budget**
Channel Assignment	**The process of choosing the RU (and its number) to be allocated to the user**
Distinction:	**1) assignment of RUs to the cells (Channel Allocation)** **2) assignment of RUs to the users within cells (Ch. Assignment)**

Radio Resource Management: Channel Allocation



Channel Allocation Techniques

Fixed (FCA): a predefined (sub-)set of channels is assigned to a base; the channel to be allocated to the user is selected among these pre-assigned channels

Dynamic (DCA): channels are in a pool, and can be selected by every base for each link

Hybrid (HCA): part of channels are allocated via FCA, part via DCA

Channel Assignment Techniques

Normally based on measurements performed on the field. **Fast (Scheduling)** or **Slow**.

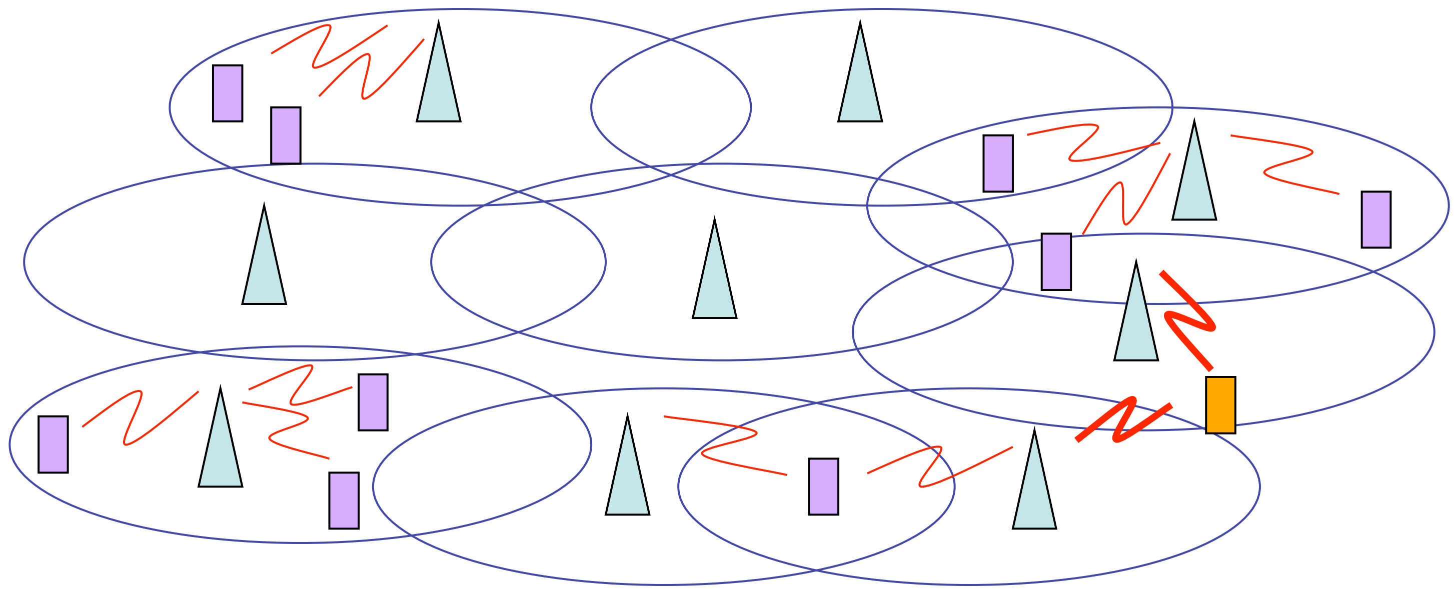
Radio Resource Management

Admission Control	**The process of determining whether a service request can be admitted to the system**
Directed Retry	**The process of re-directing a new user toward a base station different from the one providing best link budget**
Channel Allocation	**The process of choosing the channel (and the number of RUs) to be allocated to the user**
Power Control	**The process of setting the transmission power level**
Distinction:	**fast PC and slow PC**

Radio Resource Management

Admission Control	**The process of determining whether a service request can be admitted to the system**
Directed Retry	**The process of re-directing a new user toward a base station different from the one providing best link budget**
Channel Allocation	**The process of choosing the channel (and the number of RUs) to be allocated to the user**
Power Control	**The process of setting the transmission power level**
Hard Handover	**The process of changing serving base and/or RU**
Distinction:	**intra-cell handover: the RU is changed within the cell** **inter-cell handover: the serving base is changed**

Radio Resource Management: Hard Handover



One base station at a time

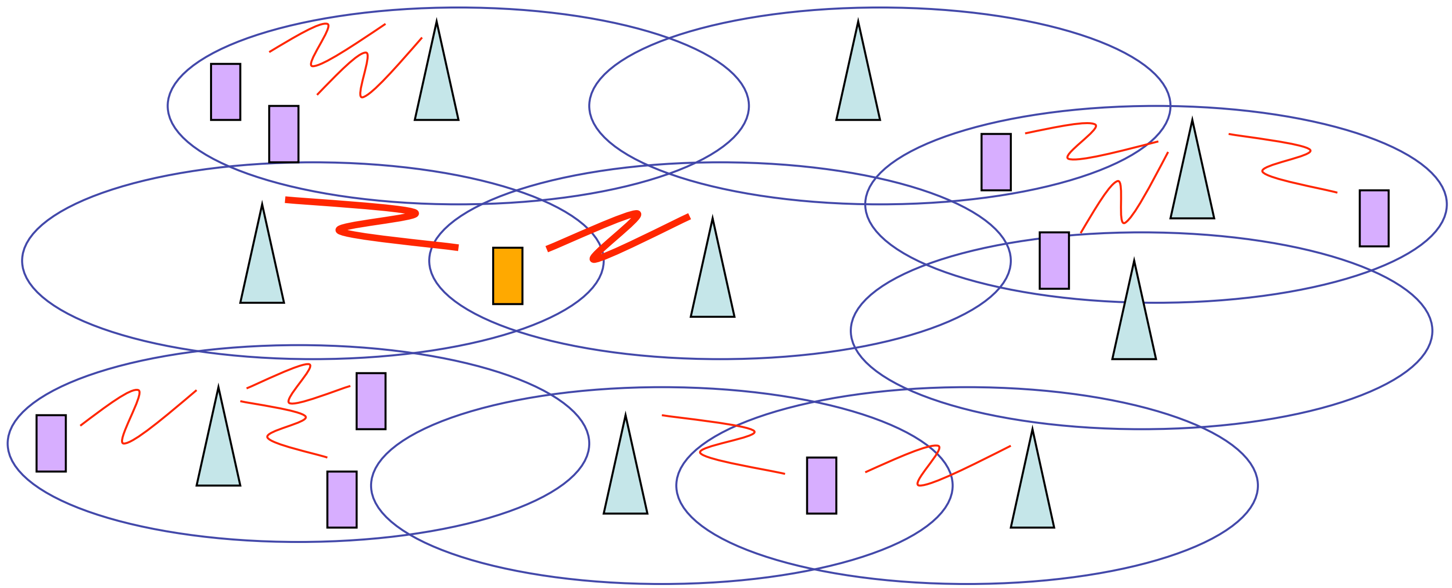
Not seamless

Can have a serious impact on the signalling channels

Radio Resource Management

Admission Control	**The process of determining whether a service request can be admitted to the system**
Directed Retry	**The process of re-directing a new user toward a base station different from the one providing best link budget**
Channel Allocation	**The process of choosing the channel (and the number of RUs) to be allocated to the user**
Power Control	**The process of setting the transmission power level**
Hard Handover	**The process of changing serving base and/or channel**
Soft/Softer Handover	**The process of modifying the set of serving bases**

Radio Resource Management: Soft Handover



More than one base station at a time

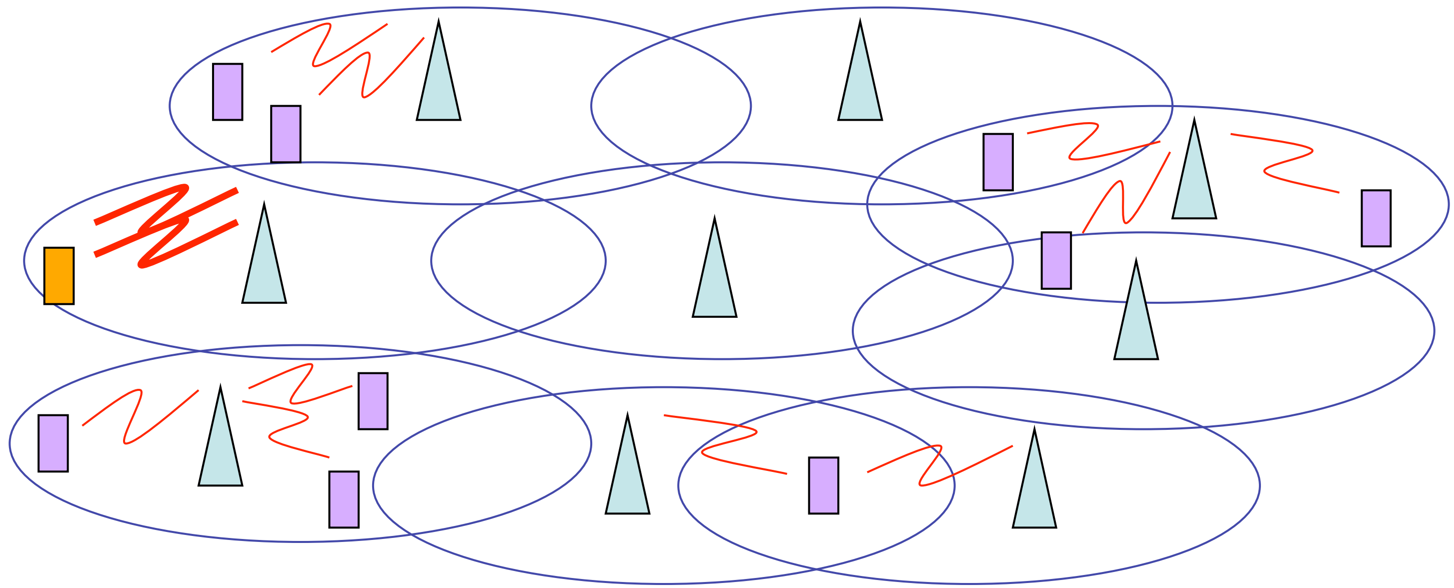
Seamless Service
Macrodiversity: reduced shadowing margin
Microdiversity: MR Combining (downlink) or S Combining (uplink)

Can have a serious impact on the network capacity

Active set

The set of
serving base stations

Radio Resource Management: Softer Handover



More than one base station within the same site at a time

Maximal Ratio Combining both on uplink and downlink

Radio Resource Management

Admission Control	**The process of determining whether a service request can be admitted to the system**
Directed Retry	**The process of re-directing a new user toward a base station different from the one providing best link budget**
Channel Allocation	**The process of choosing the channel (and the number of RUs) to be allocated to the user**
Power Control	**The process of setting the transmission power level**
Hard Handover	**The process of changing serving base and/or channel**
Soft Handover	**The process of modifying the set of serving bases**
Load Control	**The process of controlling the load of the network**