Fixed WiMAX Profit Maximisation with Energy Saving through Relay Sleep Modes and Cell Zooming

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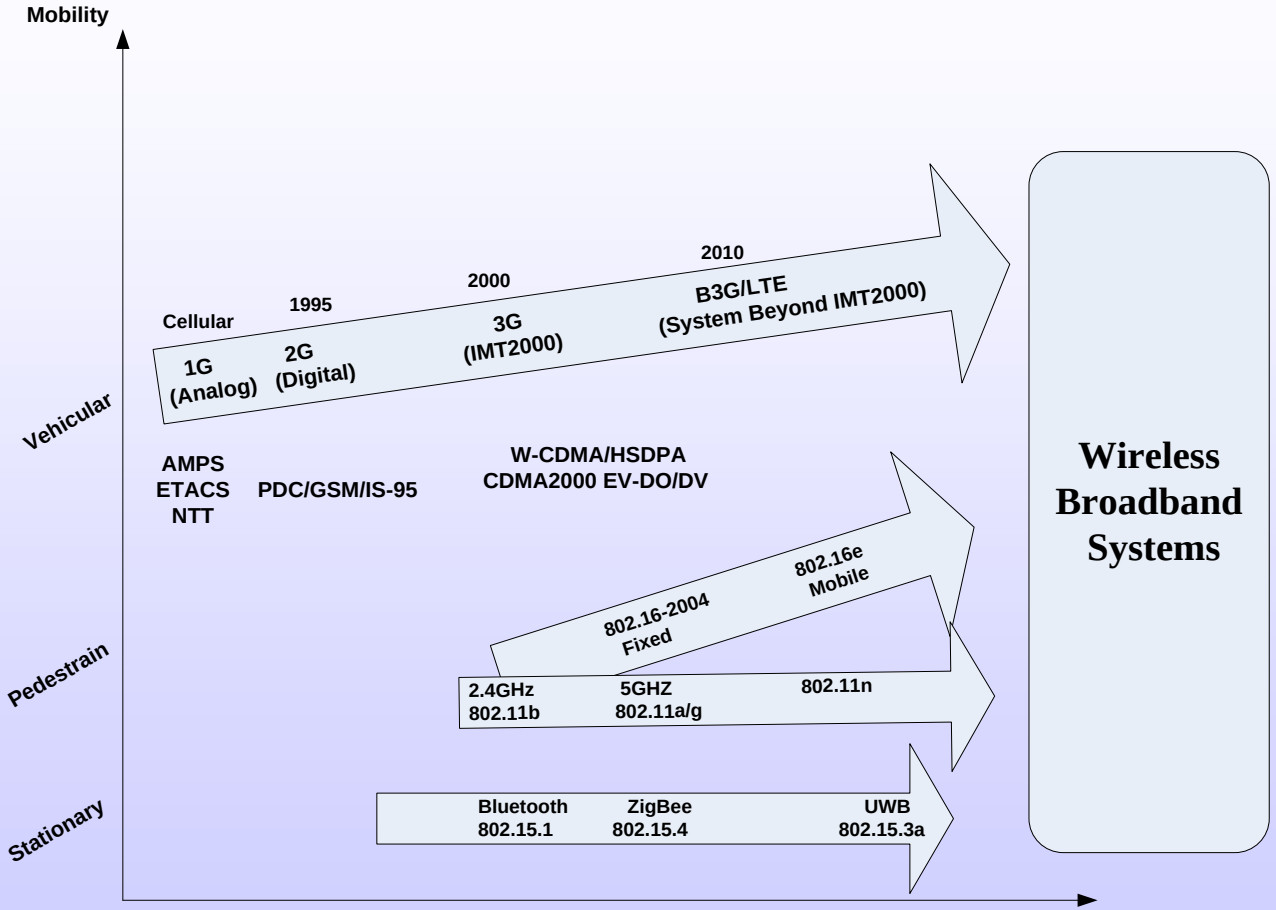
Presentation Structure

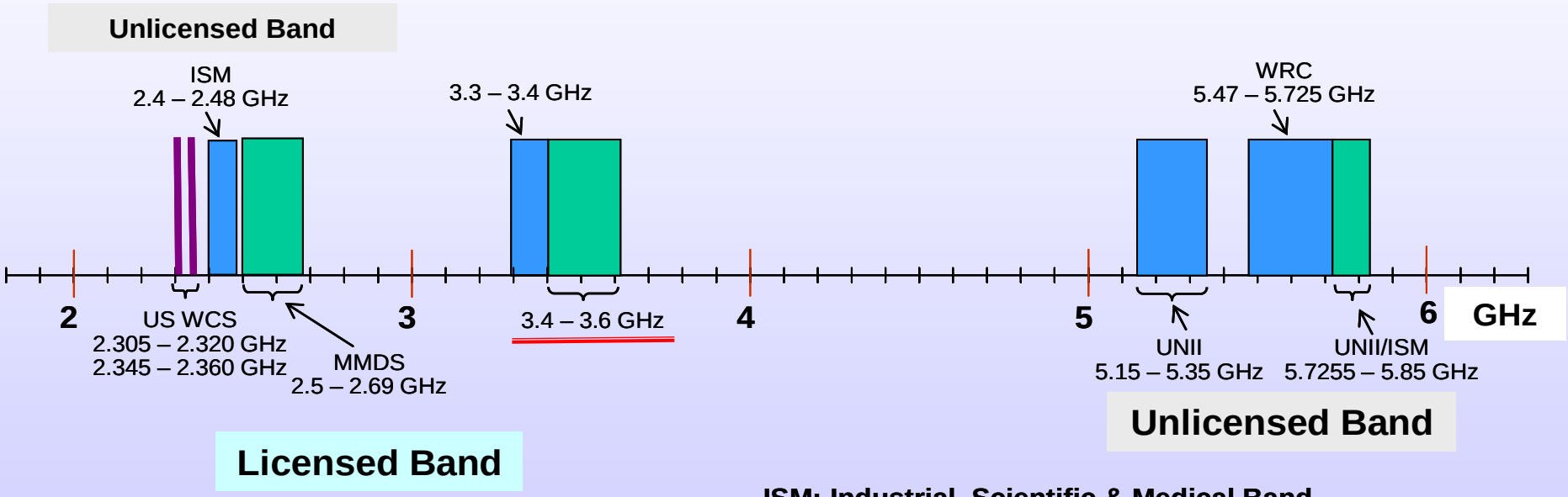
1. Evolution towards Wireless Broadband Systems
2. Fixed/mobile WiMAX spectrum and demonstrator
3. The challenge from relays & different frame formats
4. Formulation for the supported cell/sector throughput
5. Comparison between the absence and presence of Relay Stations (RSs)
6. Economic and environmental impact of cell zooming and sleep modes
7. Conclusions

Evolution of Wireless towards Wireless Broadband Systems



Data Rate	~40k	2M	14M	54M	100M	1G	b/s
Spectral Efficiency	0.4	0.4	2.8	2.7	5	10	b/s/Hz
Radio access Tecnologies	TDMA QPSK	TDMA QPSK	Adaptive QAM	OFDM/QAM Adaptive coding		MIMO Adaptive array	

2-6 GHz band available for WiMAX

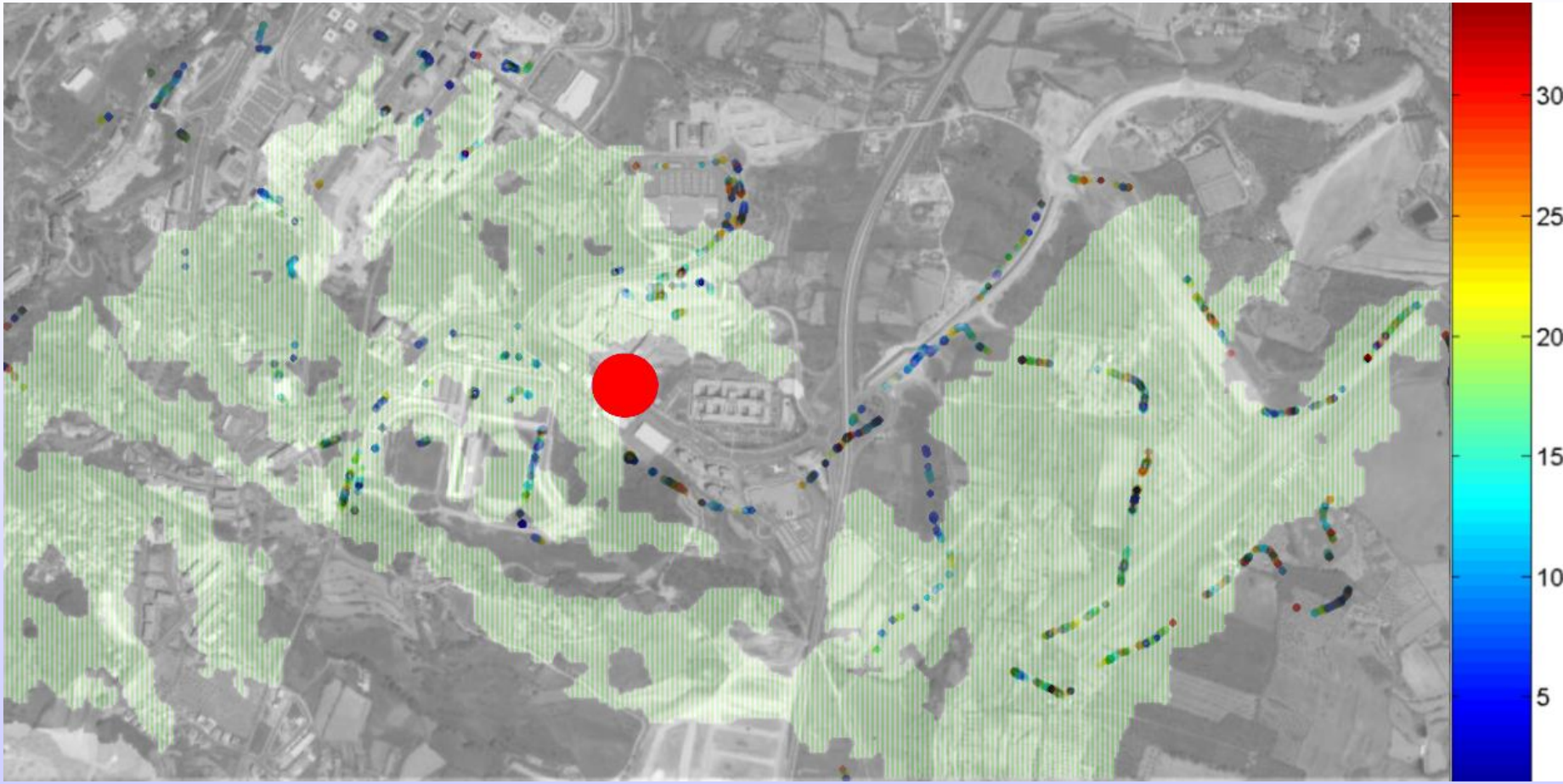


ISM: Industrial, Scientific & Medical Band
UNII: Unlicensed National Information Infrastructure band

Point-to-multipoint demonstrator at 3.5 GHz, Health Science Faculty

Signal-to-noise ratio, *SNR*, measurements

Detailed measurements of *SNR* in DL

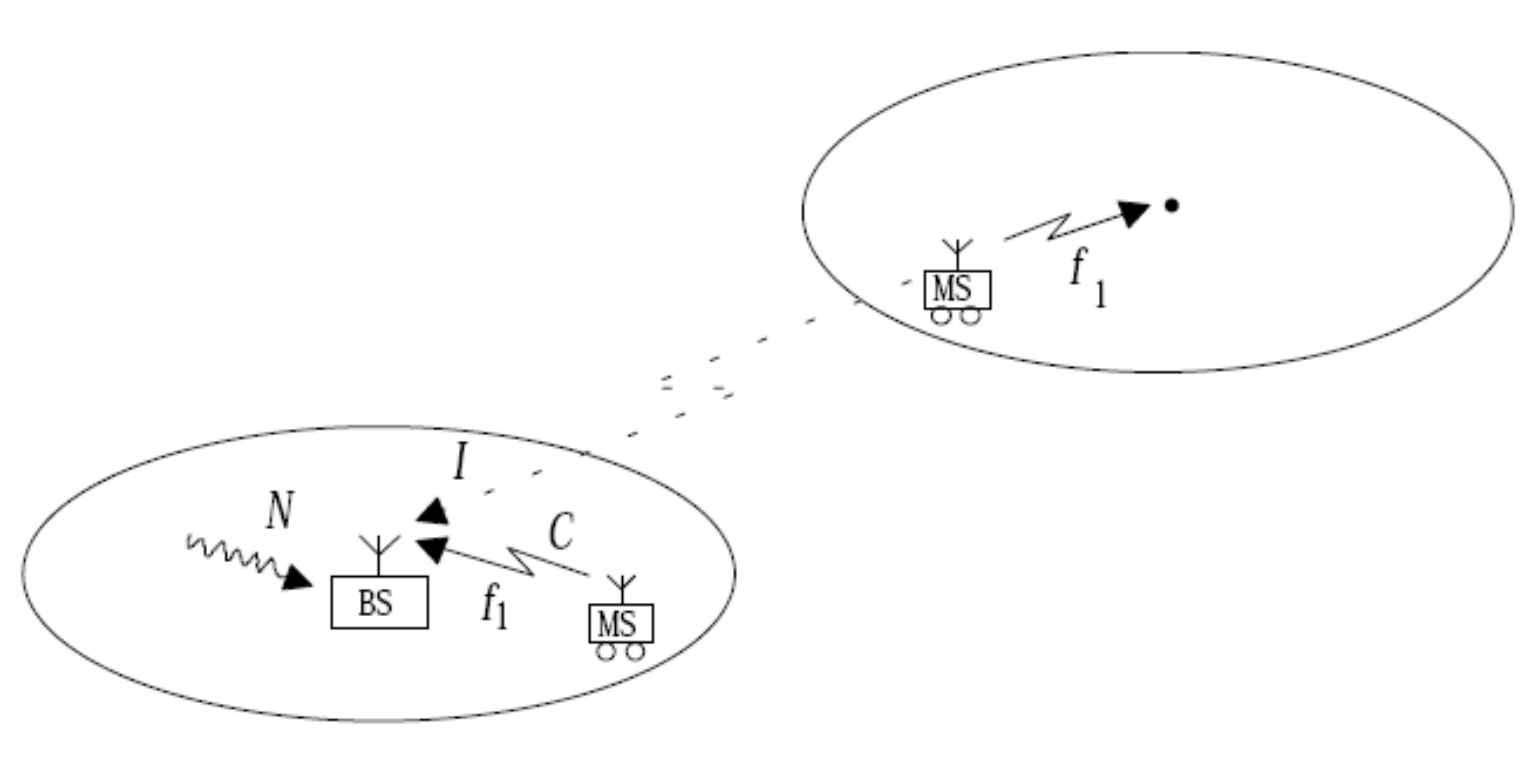


Frequency license bands:
3543-3567.5 MHz
3443-3467.5 MHz

$Throughput_{max}$ = 230 kB/s = 1840 kb/s (per SU)

16-QAM with several coding rates; however it increased to ~ 6 Mb/s after QoS classes were configured

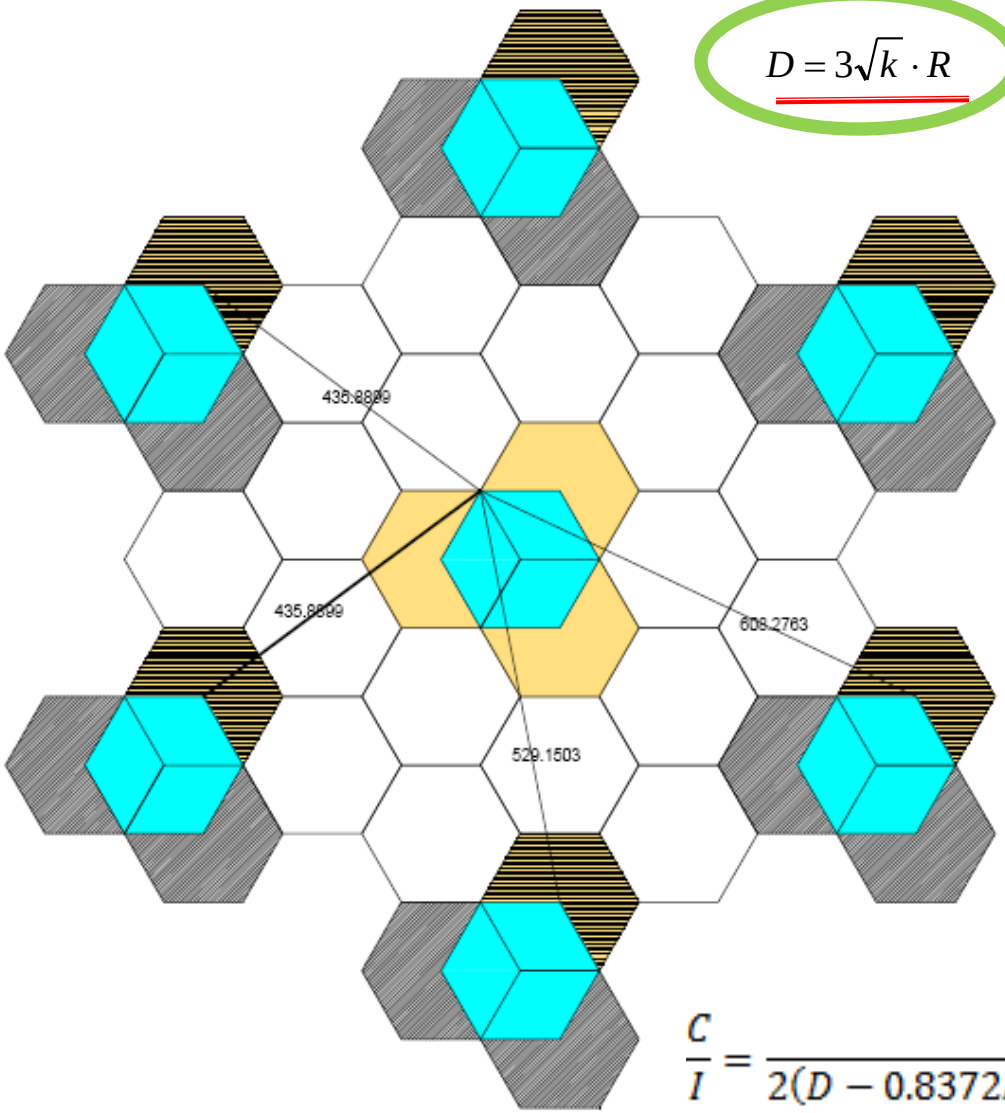
The frequency reuse problem …



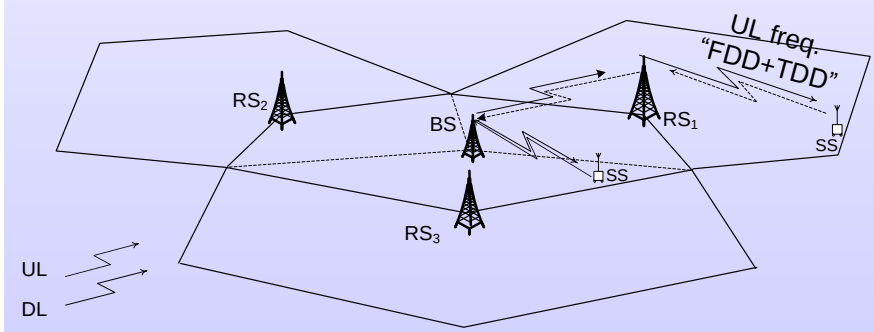
- *I* - interference power
- *N* - noise power
- *C* - power of the received carrier

Challenge: Coverage Scenario with Relays

$$D = 3\sqrt{k} \cdot R$$



- DL Scenario and 240º sector coverage in Relay Station (RS) coverage area
- The central coverage area BS may have omnidirectional or tri-sectorial antenna



D: reuse distance
R: coverage distance or cell radius

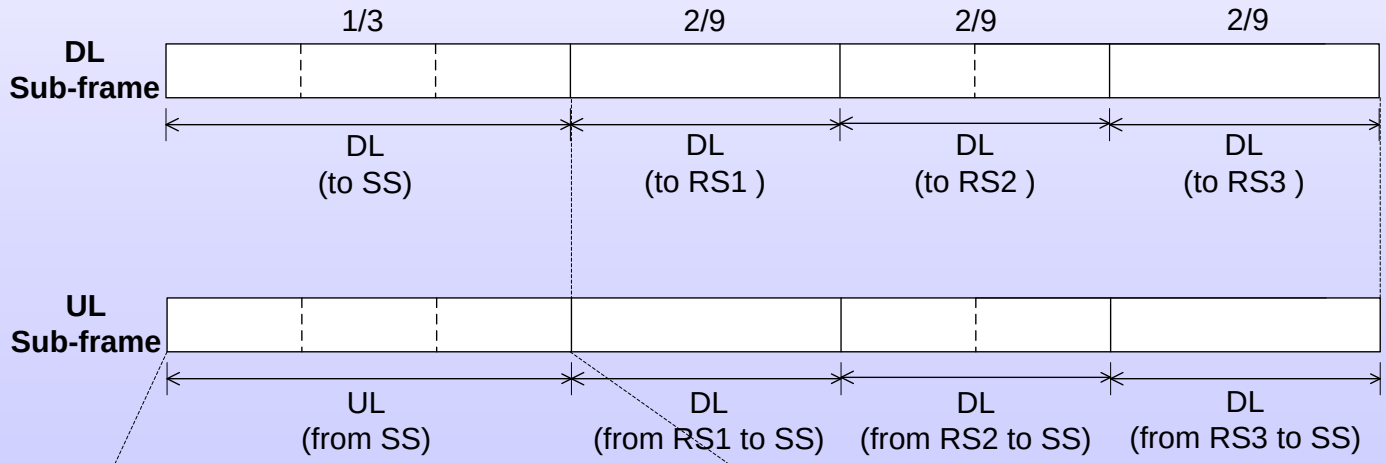
$$\frac{C}{I} = \frac{R^{-\gamma}}{2(D - 0.8372R)^{-\gamma} + (D + 0.09535R)^{-\gamma} + (D + 0.8866R)^{-\gamma}}$$

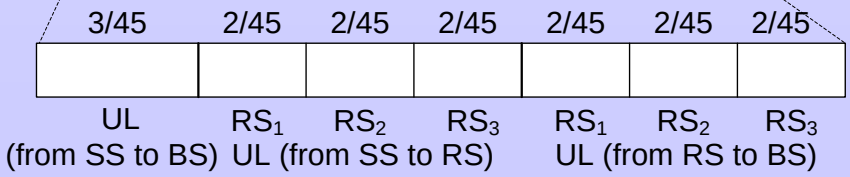
Other Challenges

- **Structure of the frames to support the use of relays:**
  - Different frame formats are enabled for *omni-directional* and *tri-sectored* central coverage zones
  - The main improvement of the “tri-sectored” frame corresponds to increase the throughput by a factor N_{sec}=3 (due to a more favourable frame format)
- **Full frame usage with no relays:**
  - Is the dynamic adaptation of the frame formats enabled?

DL and UL WiMAX sub-frames, omnidirectional BS

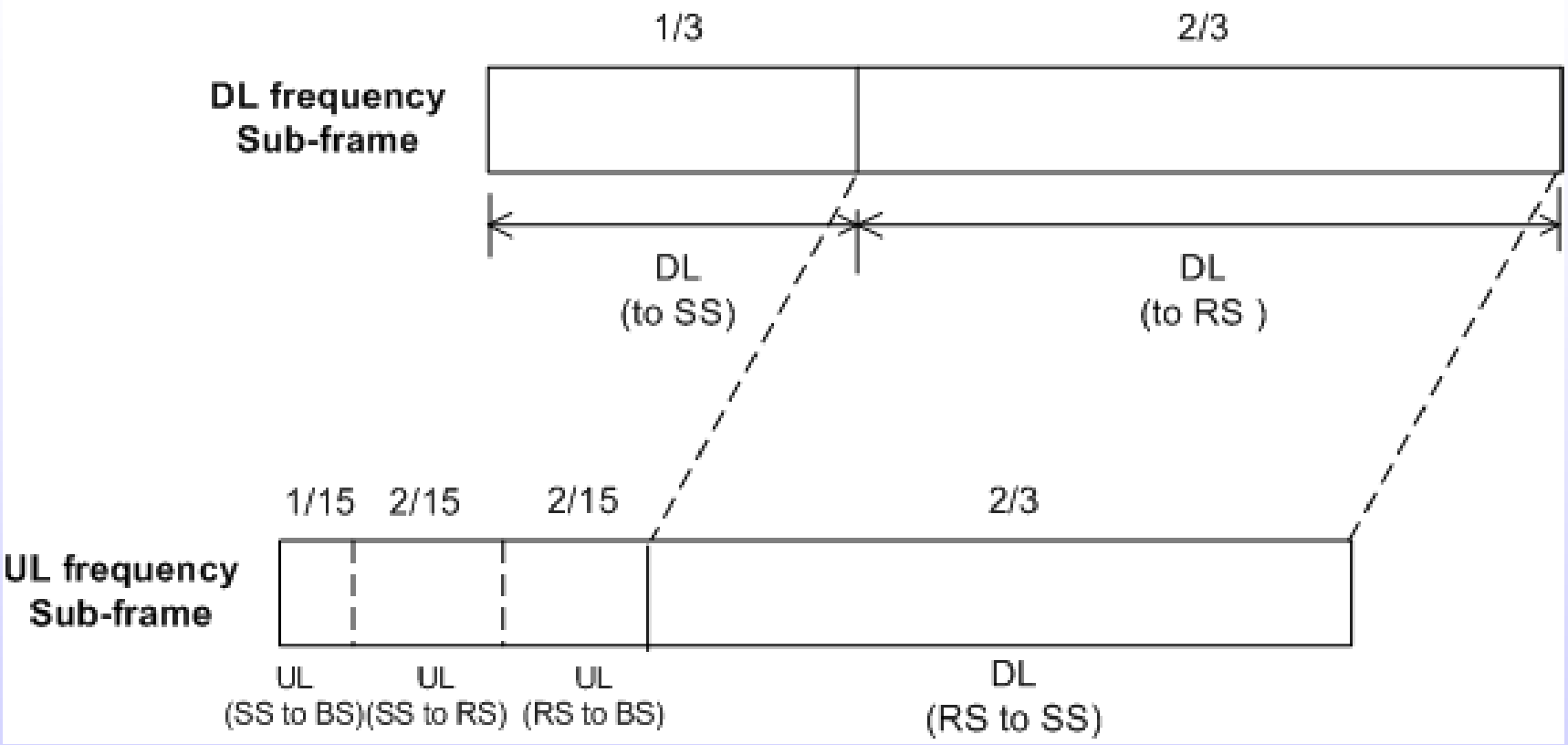
- The WiMAX frame is divided into DL and UL sub-frames which, in turn, include the following sub-divisions
  - BS to SS communication
  - BS to RS communication
  - SS to BS communication
  - RS to SS communication
  - SS to RS communication
  - RS to BS communication





The UL sub-frame supports DL communications from the RS to the SS (FDD in conjunction with TDD); assuming an asymmetry factor of 1:5 between the UL and DL, as shown in the Figure, the UL sub-frame can make extra resources available to DL RS communications

Structure of DL and UL frequency sub-frame, tri-sectored



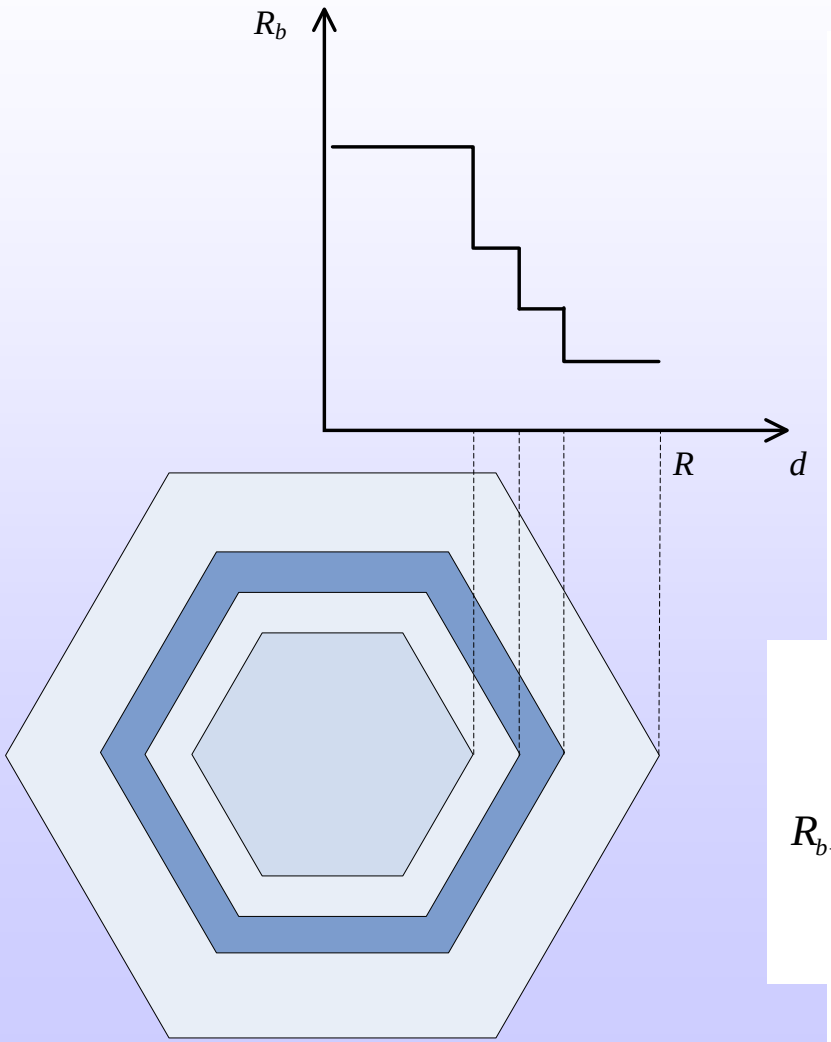
- The use tri-sect. increases the throughput by a factor N_{sec} *(at the cost of additional bandwidth)*
- Each sector only communicates with one relay
- The area covered by one relay is twice the one covered by the sector in the central coverage zone

Adaptive modulation and coding schemes

Modulation & coding	*Net PHY Bit Rate* **[Mbps]**	**Sensitivity [dBm]**
BPSK 1/2	1.41	-100
BPSK 3/4	2.12	-98
QPSK 1/2	2.82	-97
QPSK 3/4	4.23	-94
QAM 16 1/2	5.64	-91
QAM 16 3/4	8.47	-88
QAM 64 2/3	11.29	-83
QAM 64 3/4	12.27	-82

3.5GHz *Alvarion* equipment (3.5 MHz bandwidth)

Step distances for CNIR *vs* supported Physical throughput

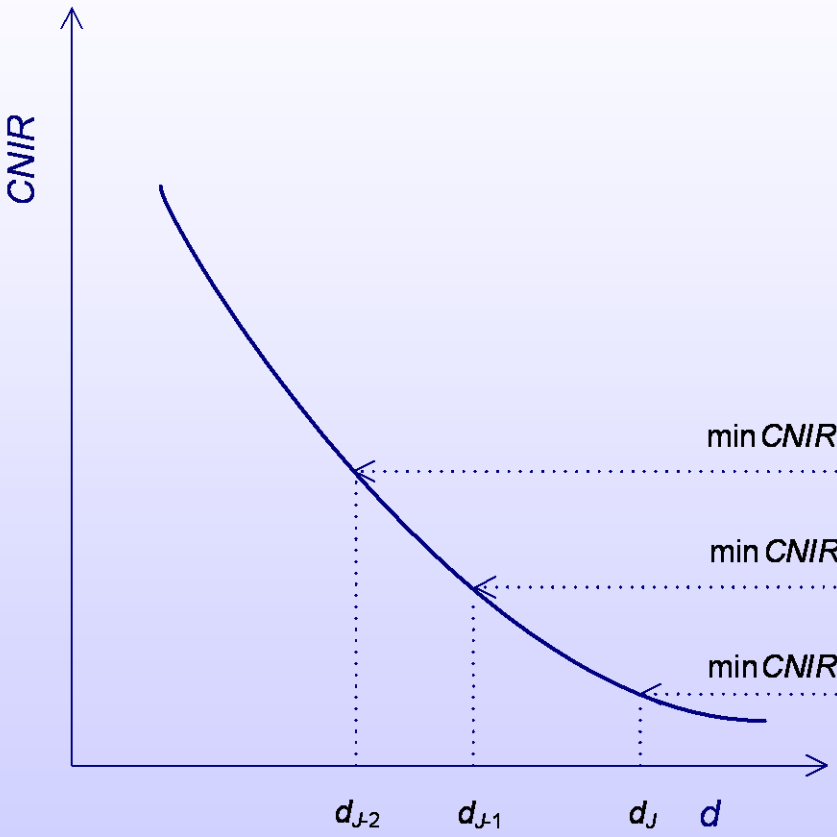


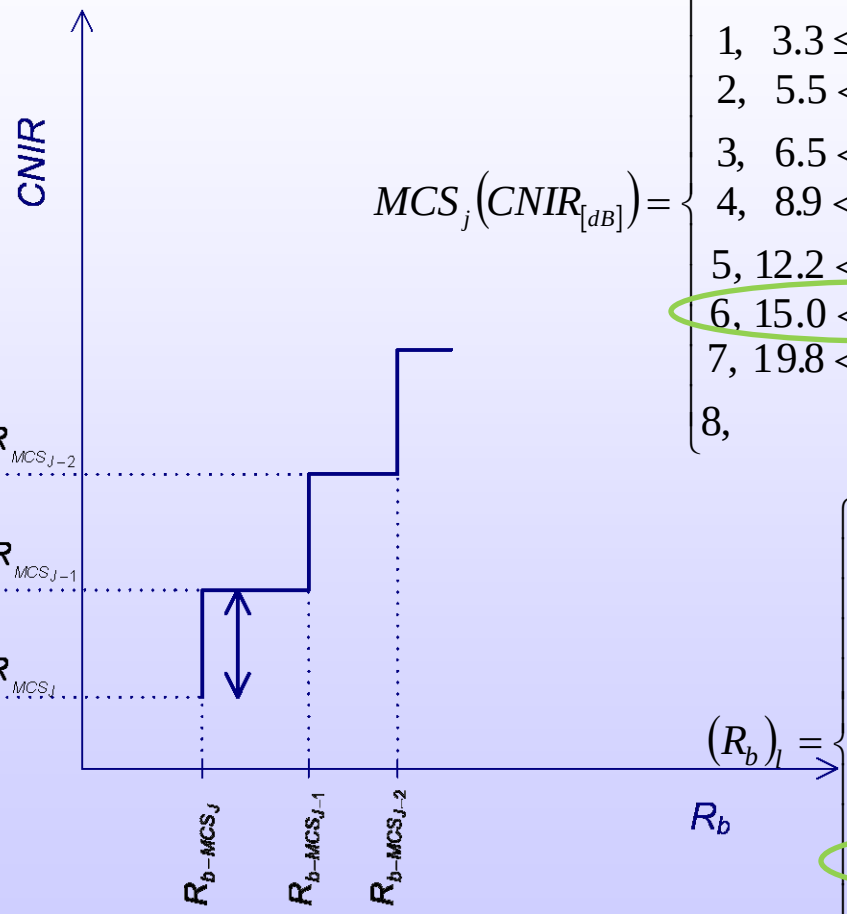
- There are J different coverage rings in a cell, each supporting a different MCS (for instance, J = 4 in Figure)
- The distances that correspond to the steps between consecutive MCS are represented by d_j, j = 1, 2, …, J. Here we denote the order of the MCS as MCS_j
- The supported throughput is obtained as

$$R_{b-\sup} = \frac{\iint_{O} R_b(d,R,K)\,dxdy}{\frac{3\sqrt{3}}{2}\cdot R^2} = \frac{\sum_{j=1}^{J}\left(\frac{3\sqrt{3}}{2}\cdot\left(d_j^2 - d_{j-1}^2\right)\cdot\left(R_b\right)_{MCS_{1st}+1-j}\right)}{\frac{3\sqrt{3}}{2}\cdot R^2}$$

where $(R_b)_{MCS1^{st}+1-j}$ is the throughput for the jth coverage ring

Rings *vs* supported PHY throughput



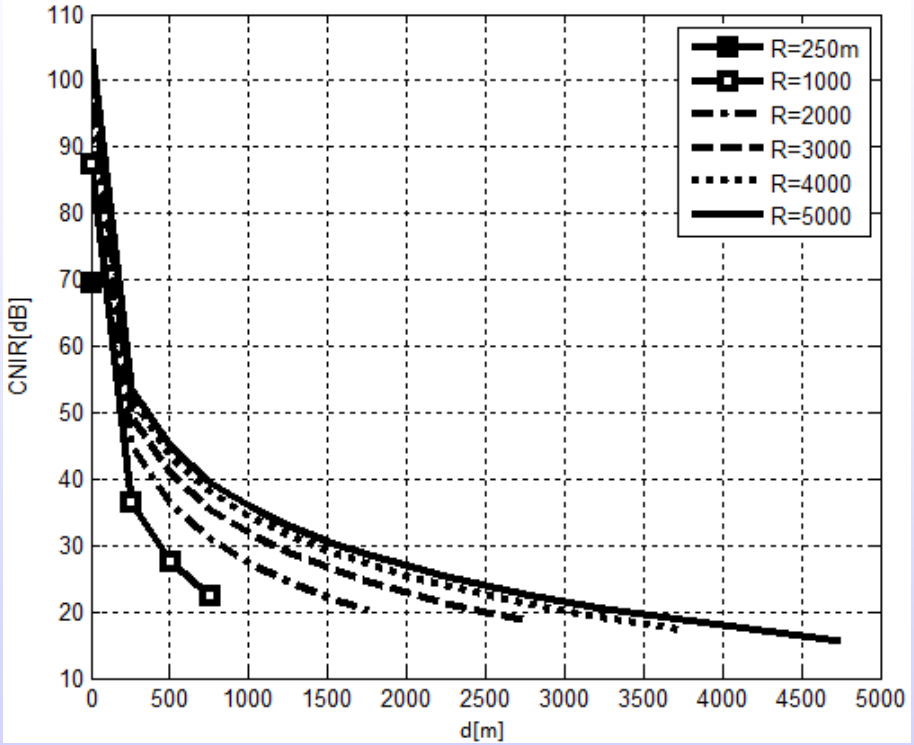


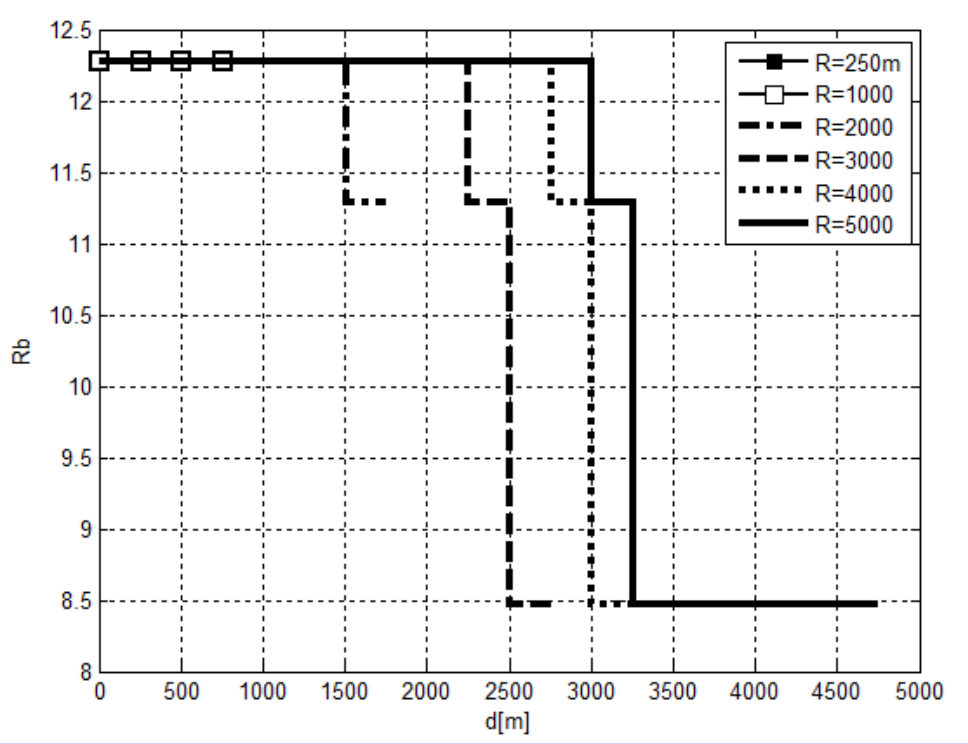
$$MCS_j\left(CNIR_{[dB]}\right)=\begin{cases}0, & CNIR<3.3\\ 1, & 3.3\le CNIR<5.5\\ 2, & 5.5<CNIR<6.5\\ 3, & 6.5<CNIR<8.9\\ 4, & 8.9<CNIR<12.2\\ 5, & 12.2<CNIR<15.0\\ 6, & 15.0<CNIR<19.8\\ 7, & 19.8<CNIR<21.0\\ 8, & CNIR>21.0\end{cases}$$

$$\left(R_b\right)_l=\begin{cases}0, & l=0\\ 1.41, & l=1\\ 2.12, & l=2\\ 2.82, & l=3\\ 4.23, & l=4\\ 5.64, & l=5\\ 8.47, & l=6\\ 11.23, & l=7\\ 12.27, & l=8\end{cases}$$

$$d_j=cnir^{-1}\left(\min\left(CNIR\left(\left(R_b\right)_{MCS_{1st}+1-j}\right)\right)\right),\ j=1,\ \ldots,\ J.$$

Correspondence between CNIR and throughput for tri-sectored BS antennas, UL, *K*=3 and subchannelisation





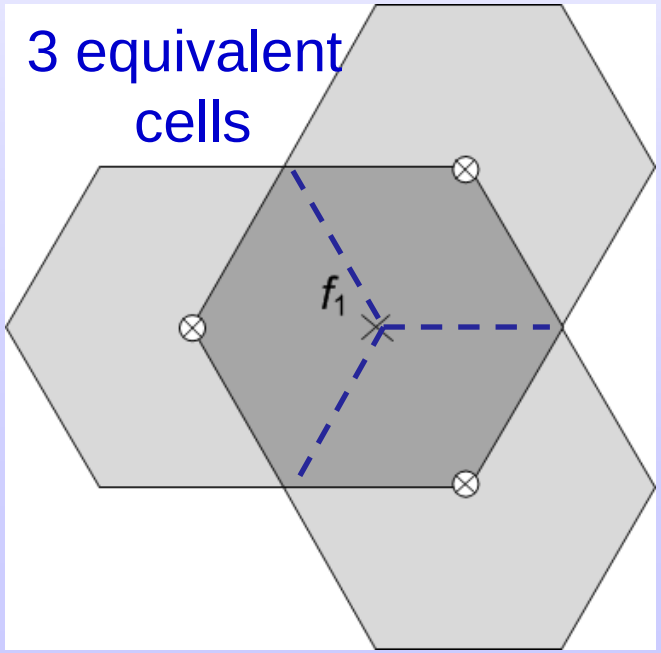
P_t = -2 dBW N_f = 3 [dB]
G_t = 17 dBi f = 3.5 GHz
G_r = 9 dBi γ = 3
b_{rf} = 3.5 MHz. (*no relays*)

The supported throughput is computed according to the formulation of the two previous slides

Contributions from the central coverage zone and RS-zone to the throughput

$$\left(R_{b-\sup}\right)_{equiv} = \frac{R_{b-tot}}{3} = \frac{N_{\sec} \cdot R_{b-central} + 3 \cdot R_{b-RS-zone}}{3} =$$

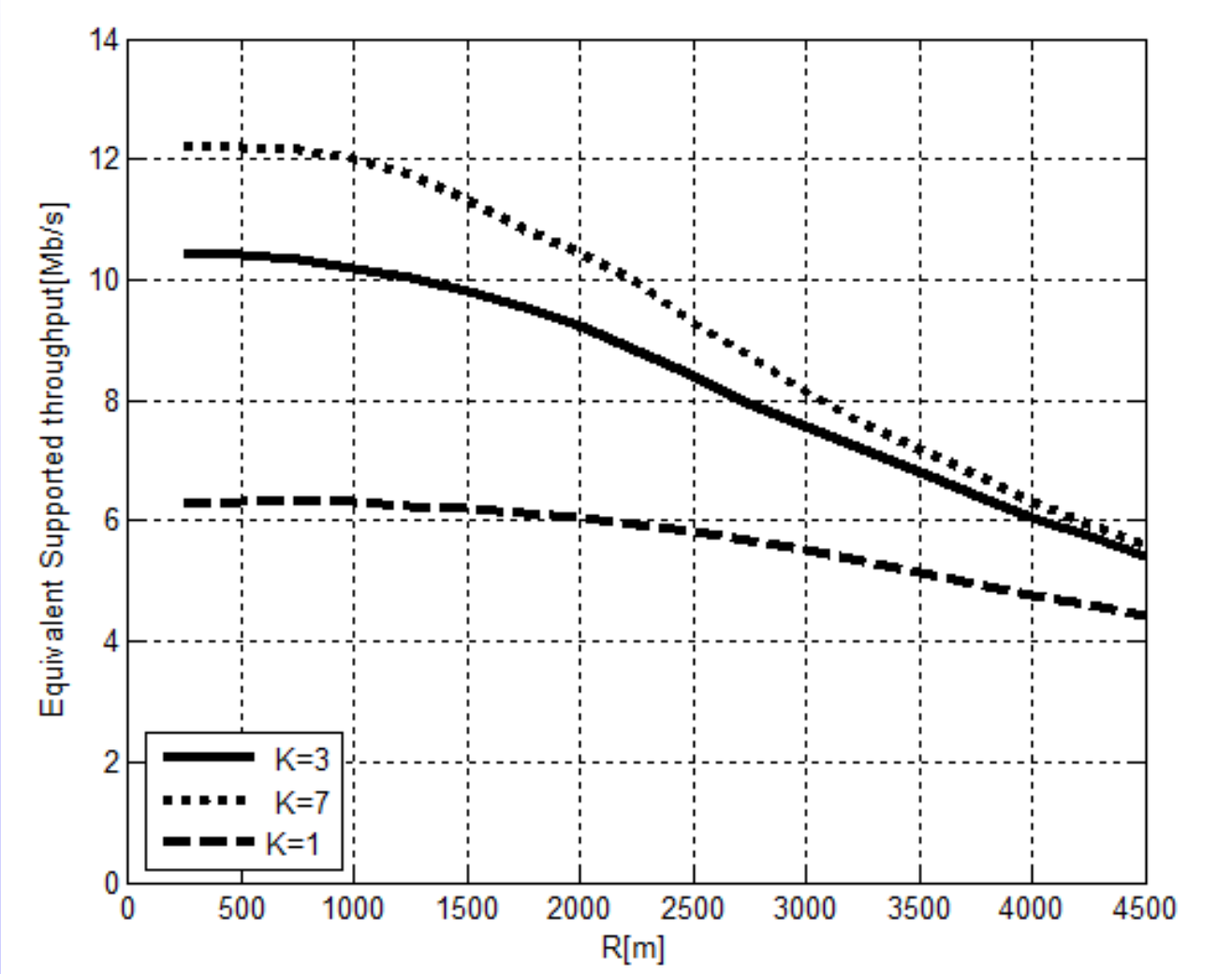
$$= \frac{1}{2} \cdot N_{\sec} \cdot R_{b-central-norm} + R_{b-RS-zone}$$



P_t = -2 dBW
G_t = 17 dBi (RS->SS)
G_r = 28 dBi (BS<->RS)
b_{rf} = 3.5 MHz.

N_f = 3 [dB]
f = 3.5 GHz
γ = 3
(*with relays*)

Equivalent Supported Throughput for Tri-sectored Cells and Relays in DL

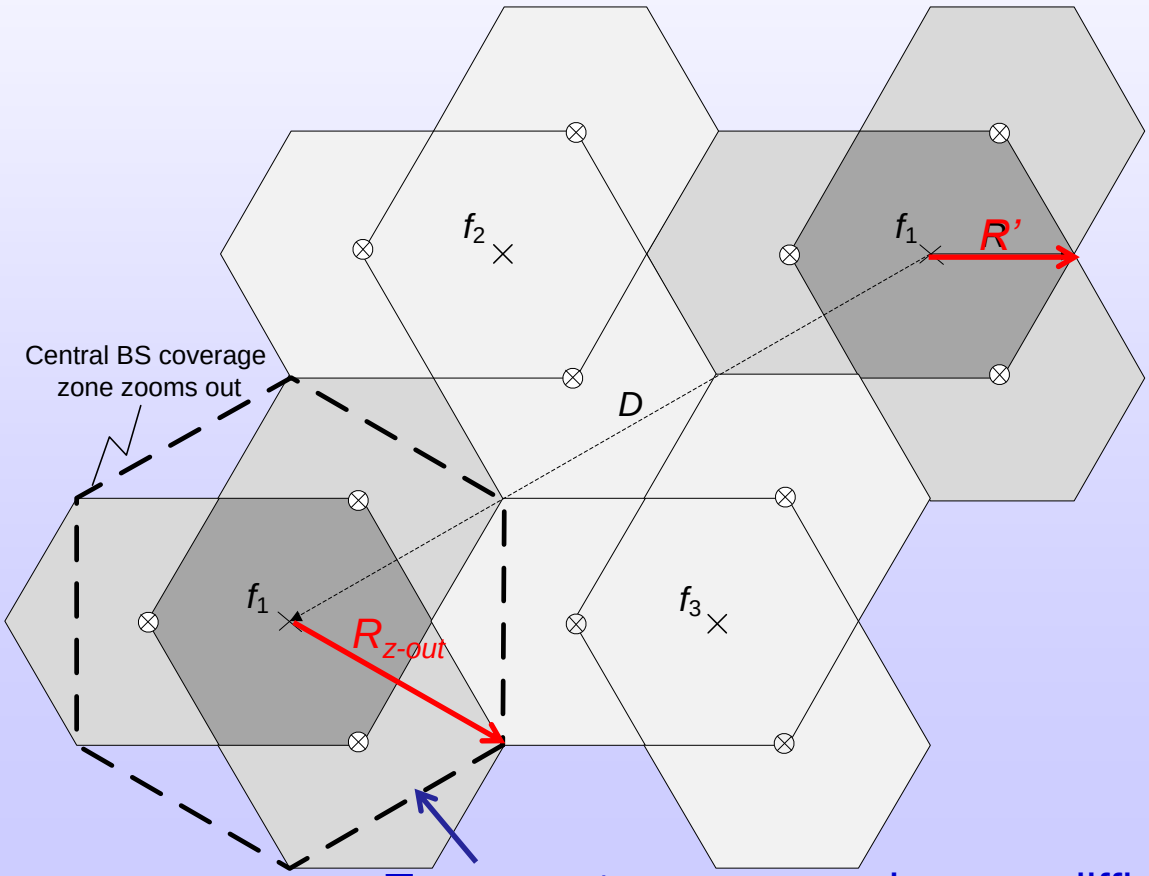


Central coverage zone zooms out
when RSs go to sleep mode

BS position

RS position

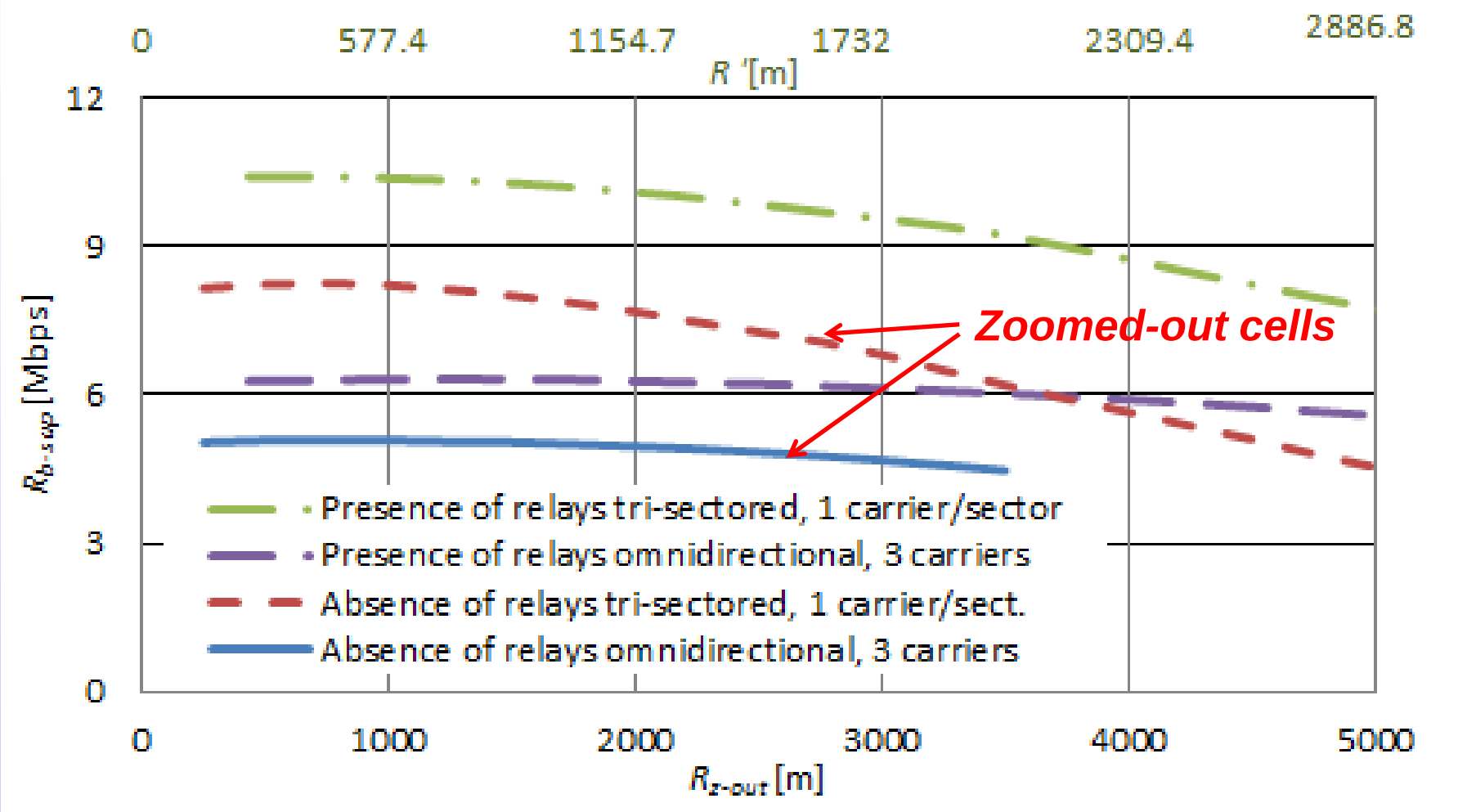
$$A_{multihop} = 3\frac{3}{2}\sqrt{3}R^2 = 3 * A_{singlehop}$$



To guarantee coverage is more difficult

Equivalent Supported Throughput with Relays and Zoomed-out Cells, *K*=3

(here *frames aren't dinamically adapted)*



Costs with relays with different antennas and *K*=1 (one carrier per cell/sector)

Costs	Omnidirectional	Tri-sectored
C_{fi} [€/km2]	15.63	47.14
C_{BS} [€]	7680	6800
C_{Inst} [€]	1333.33	2000
C_{bh} [€]	833.33	833.33
$C_{M\&O}$ [€/year]	833.33	833.33

Equivalent cell / BS

C_{fi} – fixed term of the costs

C_{BS} – cost per BS

C_{inst} – installation cost

C_{bh} – cost for the normal backhaul

$C_{M\&O}$ – cost of the maintenance and operation

Revenues

A given price for 1 MB of information is assumed, e.g., 0.005 €/MB

Revenue and *Profit*

- The cost per unit area is given by:

$$C_{[€/km^2]} = C_{fi[€/km^2]} + C_b \cdot N_{cell/km^2}$$

where C_{fi} is the fixed term of the costs, C_b is the cost per BS

- The cost per BS is given by:

$$C_b = \frac{C_{BS} + C_{bh} + C_{Inst}}{N_{year}} + C_{M\&O}$$

- The (absolute) profit is given by (R_v is the revenue per unit area):

$$P_{[€/km^2]} = R_v - C,$$

from which, the profit in percentage terms is given by:

$$P_{[\%]} = \frac{R_v - C}{C} \cdot 100.$$

Energy saving when RSs are switched-off

- **An additional challenge has been to optimize the energy saving when RSs are switched-off during either the night period or the weekends, when the traffic load is low**
- **In these periods:**
  - although the value for the BS transmitter power is kept the same, the central coverage zone of the cell is zoomed out
  - the *offered traffic* significantly decreases and RSs may sleep whilst increasing the range of the central coverage zone of the cell; when a RS is working at the sleep mode, the air-conditioner and other energy consuming equipment can be switched-off.
- **The coverage zones of the RSs in the sleep mode zooms in to 0 and the central BS coverage zone zooms out to guarantee the coverage of the cell**

Power consumption parameters for the BSs and RSs

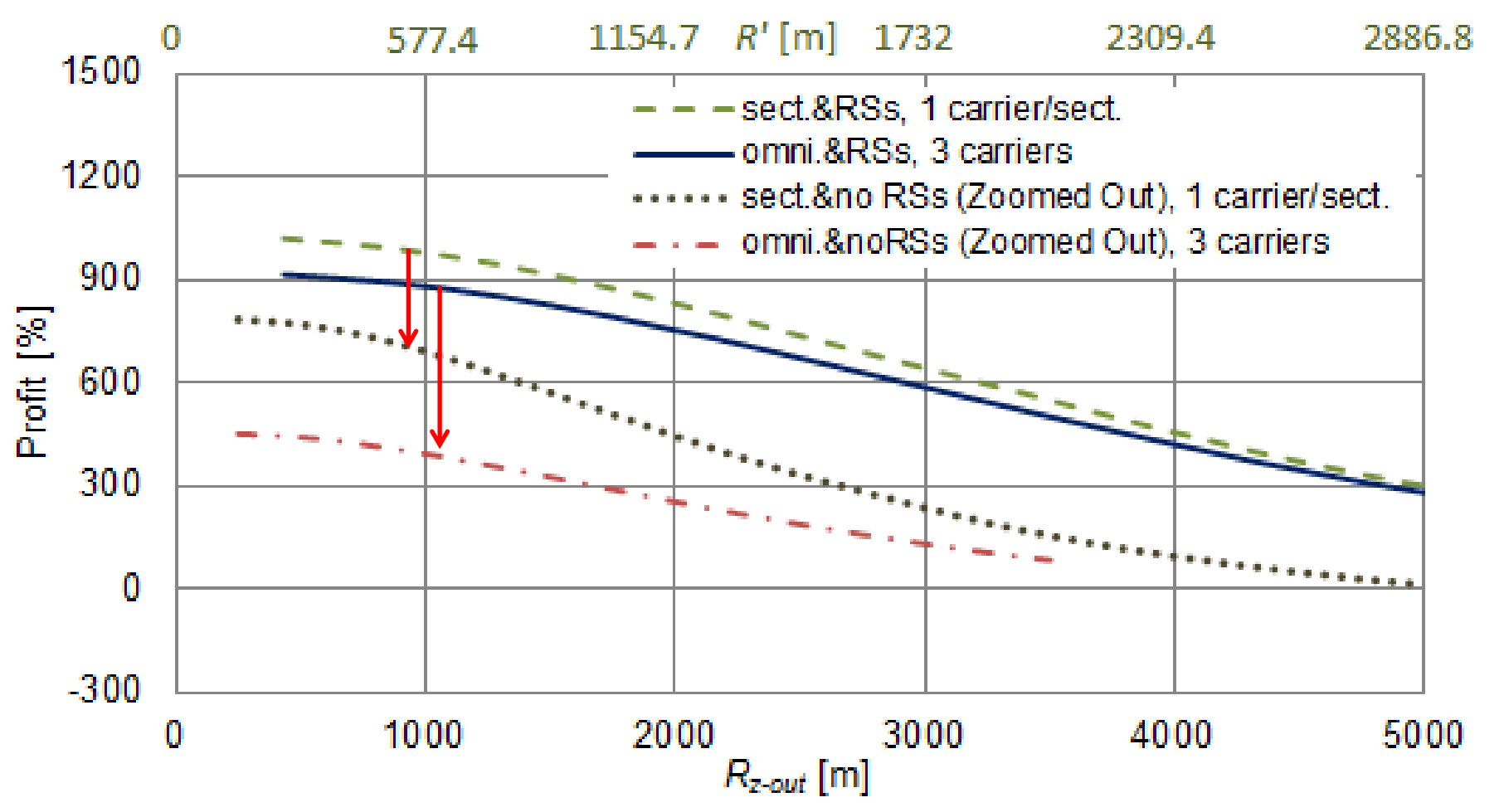
Station	BS		RS
	Tri-sectored	Omni.	
Power for the full chassis [W]	420		80
Number of sectors	3	1	-
Power for the outdoor unit(s) [W]	120	40	80
Total power of BS/RS equipment alone [W]	540	460	160
Power consumption for the router/switch [W]	100		-
Power consumption for the ventilator [W]	40		20
Total power consumption for the stations [W]	680	600	180
Annual energy consumption [kW·h]	6000	5250	1750

- During whole year, the total energy waste in RSs is 24·365·540=4730.4 kW·h → electricity cost = 473.04 €/year (@ 0.10 €/kW·h)
- If the RSs are switched-off overnight (for eight hours each night during the working days) and during the whole weekend (48 hours) => the energy is saved for 5·8+2·24 = 88 hours (against 80 hours of full functionality cell operation), i.e., 47.6% (~50%) of the time in full operation.

Economic and environmental impact of cell zooming

- **Therefore, by switching-off the three RSs of each cell there is a reduction in the annual cost per cell of 247.17 €/year**
- **The aforementioned reduction in the cost per cell corresponds to a reduction of the operation costs of the 'equivalent BS' of 247.17/3 = 82.62 €/year (~10% of $C_{M\&O}$)**
- **NOTE:**
  - We assume here the DL sub-frame format *cannot* be changed (to a more favourable one) when the RSs are switched-off
  - Note the ~ 83 €/year reduction in the operation and maintenance costs are reflected in the computations for the zoomed out central BS coverage zone cell (in the no RSs case).

Comparison between omni. (3 carr.) and tri-sect. (1 carr./sect.) with *Cell Zooming*



Conclusions

- **Relays are cheaper than full-functionality BSs**
- **With Relays, the need of resources for BS-to-RS communications causes a decrease in throughput (only partially compensated by sectorization)**
- **During the low traffic periods, zooming out the central coverage zone and zooming the RS coverage zone in to 0 yields 50 % of energy saving in RSs (~25% saving in the whole cell with relays)**
- **If the dynamic adaptation of frames is not allowed, as the throughput decreases, the economic performance is lower (but still kept at reasonable values)**

Conclusions (cont.)

- **However, it is important to highlight that in the absence of RSs, in the case of the zoomed out central BS coverage zone (with these RSs in the sleeping mode and its cooling system switched-off), *the economic performance is still reasonable***

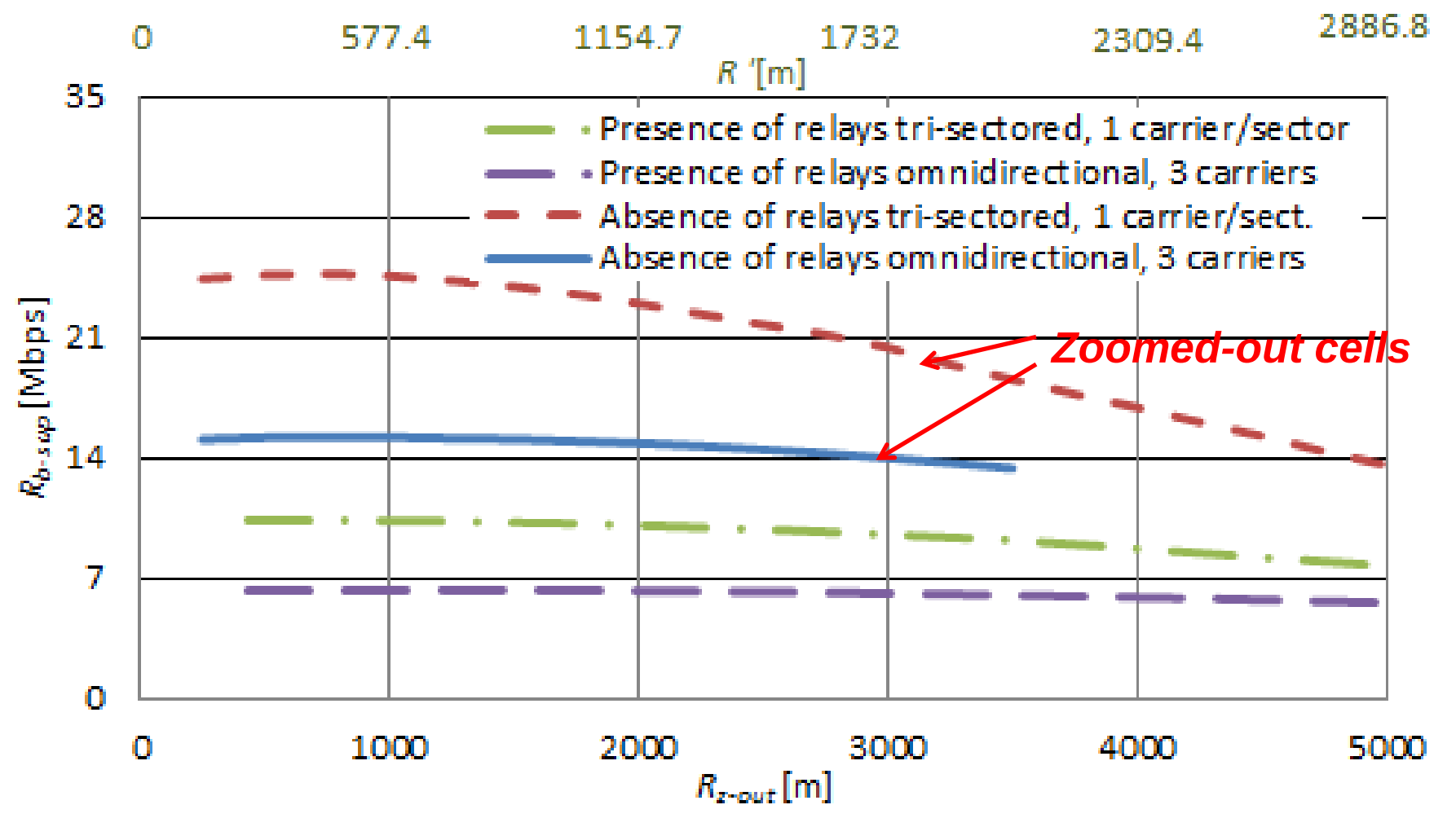
	Profit [%]	
Type of cell	*With RSs*	*Cell Zooming*
Omnidirectional	900	400-450
Tri-sectored	~1000	700-800

- **As, during the night and weekends the offered traffic is low, the switch-off of the RSs has the clear advantage of the power saving, and yields an important economic impact**

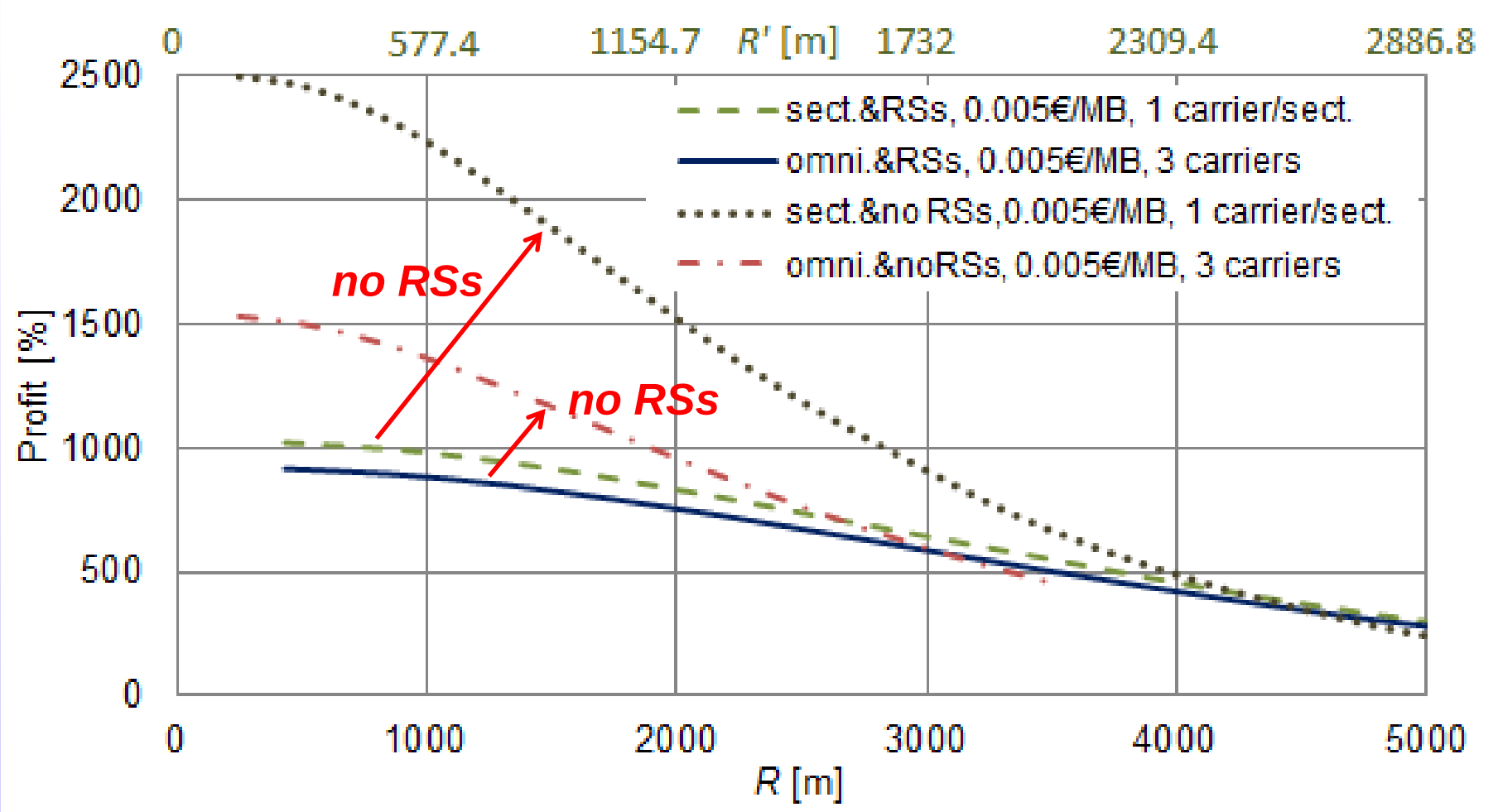
Mobile WiMAX BS at 5.4 GHz

Equivalent Supported Throughput for Cells with Relays and Zoomed-out Cells

(frames may be dynamically adapted)



Comparison between omni. (3 carriers) and tri-sect. (1 carrier/sect.)



…but better coverage is achieved with RSs