IMPACT OF MULTI-ANTENNA SCHEMES AND FEQUENCY REUSE ON BROADBAND OFDM SYSTEM LEVEL PERFORMANCE

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Challenges Addressed

- **Multi-Antenna Schemes** (MIMO, beamforming, spatial multiplexing)
  - Maximize throughput and power efficiency
  - Highly dependent on the feedback scheme that attempts to model the true SNIR affected by
    - Fast Channel variations due to multipath and user speed.
    - Interference from neighbouring base station.
  - Tradeoff between performance and signalling cost.

- **Frequency Reuse Factor Optimization Schemes**
  - For an operator, one of the most important assets is the frequencies it has.
  - Efficient usage of frequencies – optimum frequency reuse- leads to interference reduction and to throughput enhancement

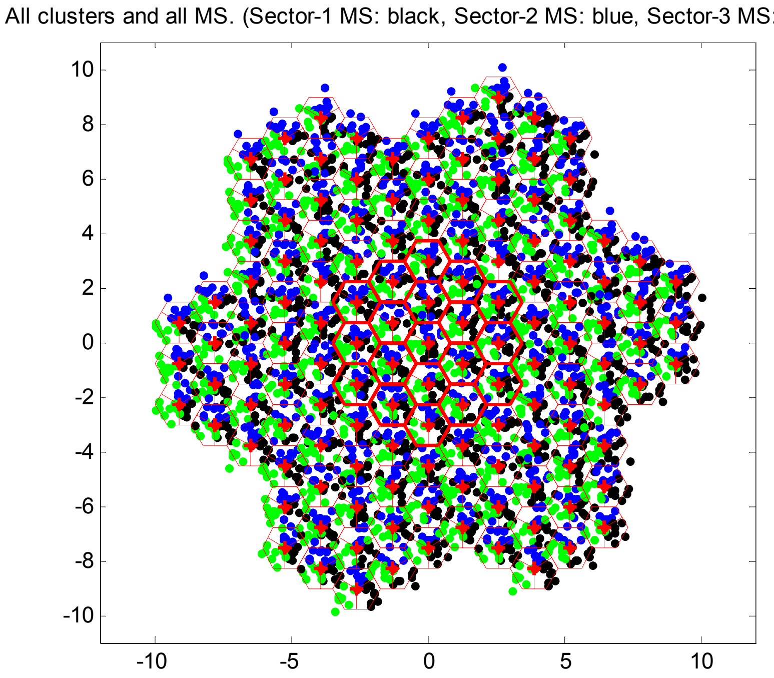
- **The combination of MIMO schemes and frequency reuse plans is studied using the developed system-level simulator**

Techniques Addressing the Challenges

- **Studied MIMO Techniques**
  - SIMO 1x2
  - MIMO 2x2 (Matrix A, i.e. Alamouti)
  - Distributed MIMO employing Spatial Multiplexing and Beamforming
  - Comparison with SISO (baseline)

- **Studied Frequency Reuse Factor Optimization Schemes**
  - Interference coordination technique in OFDMA systems. Formulation of an optimization problem and solution via a linear interior point method.
  - Determination of the frequency reuse factor of the cell exterior zone and the percentage of the overall system bandwidth that should be attributed to both interior and exterior zones.

SİMULATİON MODEL



- The system is modeled as a network of 7 clusters and each cell has three sectors.
- The cellular structure in baseline scenario includes 7x570 mobile stations and 7x19 base stations.
- There are three sectors in all the cells: black, blue and green MSs are connected to sector-1, 2 and 3, respectively.
- Traffic is always full buffer. The size of FEC blocks varies with the modulation and coding scheme to obtain the best goodput performance. In other words, the size of FEC blocks varies depending on goodput performance.
- CQI information is perfect but 3 frames delayed as stated in the EMD.
- The channel model and sample simulation parameters are detailed in the next slide.

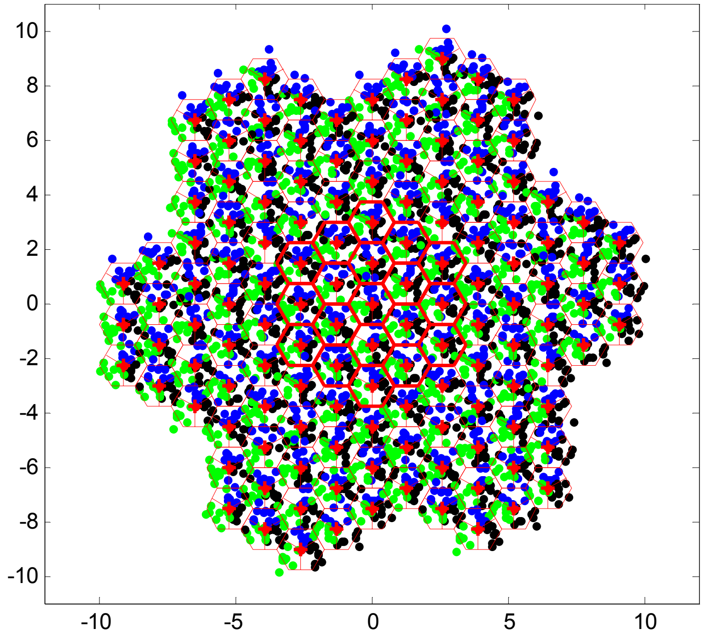
SAMPLE SİMULATİON PARAMETERS

Requirement	Baseline Configuration (Calibration & SRD) TDD and FDD
Site-to-Site Distance	1.5 km
Carrier Frequency	2.5 GHz
Operating Bandwidth	10 MHz for TDD / 10 MHz per UL and DL for FDD
BS Height	32 m
BS Tx Power per sector	46 dBm
MS Tx Power	23 dBm
MS Height	1.5 m
Penetration Loss	10 dB
Path Loss Model	Loss (dB) = 130.19+37.6$\log_{10}$(R in km)
Lognormal Shadowing Std. Dev.	8 dB
Correlation Distance for Shadowing	50m
Mobility	0-120 km/hr
Channel Mix	ITU Ped B 3 km/hr – 60, % 30 km/hr – 30%, 120 km/hr – 10%
Spatial Channel Model	ITU with spatial correlation Refer to Section 3.2.9 ***)
Error Vector Magnitude (EVM)	30 dB

Base Station Model		Mobile Station Model	
Max transmit power per sector/carrier	46 dBm @ 10 MHz bandwidth	RMS transmit power/per SS	23 dBm
Base station height	32m	Subscriber station height	1.5 m
Gain (boresight)	17 dBi	Gain (boresight)	0 dBi
Number of sectors	3	Gain as a function of Angle-of-arrival	Omni
3-dB beamwidth	$S=3, \phi_{BS}=70^0$	Number of transmit antennas	1
Front-to-back power ratio	20 dB	Number of receive antennas	2
Number of transmit antennas	2	SS antenna spacing	$\lambda/2$
Number of receive antennas	2	Noise figure	7 dB
BS antenna spacing	4λ	Cable Loss	0 dB
Noise figure	5 dB		
Cable loss	2 dB		

HOW TO SİMULATE

All clusters and all MS. (Sector-1 MS: black, Sector-2 MS: blue, Sector-3 MS: green)



- Mobile stations are randomly dropped over the 57 sectors such that each sector has the required numbers of users.
- Users dropped within 35 meters of a sector antenna shall be redropped. MS locations for the other six clusters around the centre cluster are the same as the centre cluster.
- The location of each MS remains unchanged during a drop, and the speed of an MS is only used to determine the Doppler effect of fast fading. Additionally, the MS is assumed to remain attached to the same BS for the duration of the drop.
- Mobiles are randomly assigned channel models. Depending on the simulation, these may be in support of a desired channel model mix, or separate statistical realizations of a single type of channel model.
- MSs are assigned a specified traffic type. (Full Buffering for the results in this presentation)

HOW TO SİMULATE (contn)

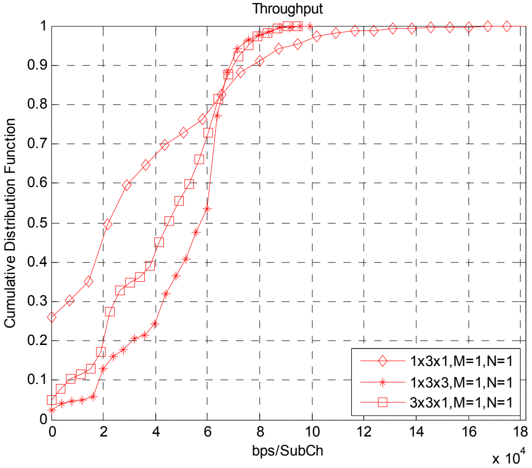
- Interference to each connection is calculated with a computationally simple and efficient method.
  - Determine the path loss, BS antenna gain, and shadowing from all interfering sectors to MS.
  - Rank the interfering sectors in order of received power (based on path loss, BS antenna gain, and shadowing).
  - Obtain the fading channel coefficients of the strongest 8 interferers. Calculate the total interference from the strongest 8 interferers taking into account path loss, BS antenna gain, shadowing, and fast fading variations.
  - Model the interference from the remaining sectors as spatially white Gaussian noise processes whose variances are based on a spectrally flat Rayleigh fading process. At any instant in time, the total received interference power is the summation of the receive power from of all weak interferers.
- Packets are not blocked when they arrive into the system (i.e. queue depths are infinite). Users with a required traffic class shall be modeled according to the assigned traffic model.
- Packets are scheduled with a proportional fair packet scheduler. Channel quality feedback delay, PDU errors are modeled and packets are retransmitted as necessary. The HARQ process is modeled by explicitly rescheduling a packet as part of the current packet call after a specified HARQ feedback delay period.
- All 57 sectors in the centre cluster are dynamically simulated for each frame (5 ms).
- Performance statistics are collected for MSs in all sectors in the centre cluster.

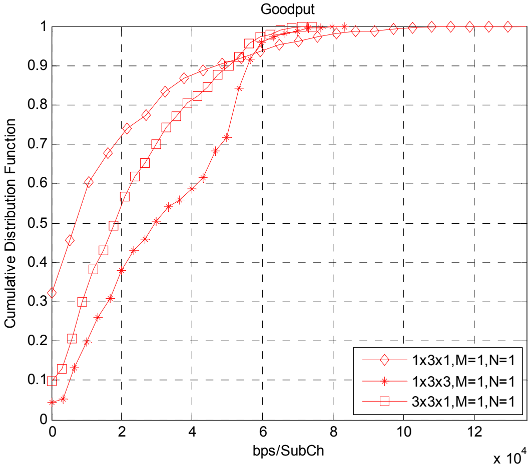
SUMMARY OF RESULTS

Simulation results can be summerized by the following items

- Frequency Reuse Modes
  - SISO, 1x2 SIMO, 2x2 MIMO Alamouti
    - Reuse: 1x3x1 , Reuse: 3x3x1, Reuse: 1x3x3
- Antenna Scheme
  - Reuse: 1x3x3
    - SISO, 1x2 SIMO, 2x2 MIMO Alamouti
- Number of User
  - (SISO; Reuse: 1x3x3)
    - NoU:5, NoU:10, NoU:20, NoU:30

FREQUENCY REUSE MODES (SISO)



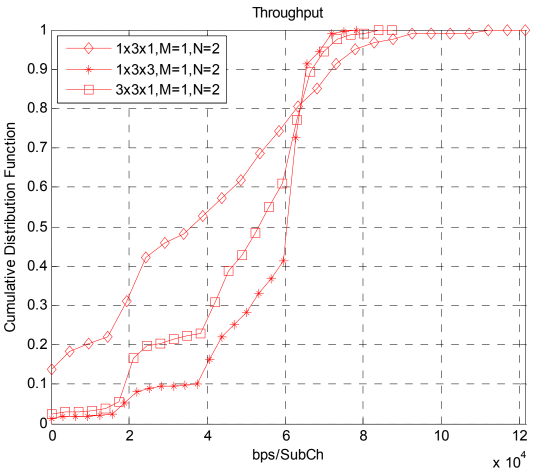


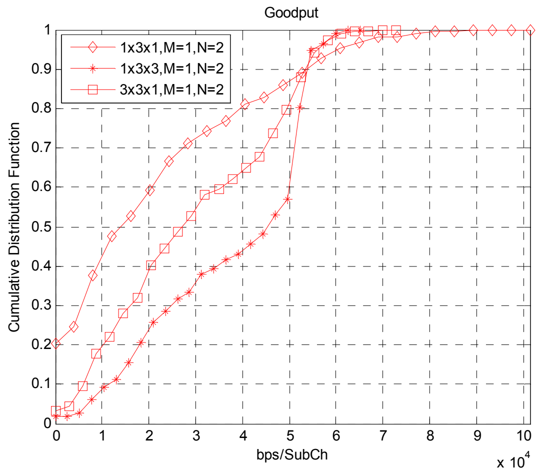
- The 1x3x3 case yields the best performance in terms of sectoral spectral efficiency and packet error rates owing to the reduced intra-cell interference.

- The 3x3x1 case cannot take complete advantage of interference mitigation as the 1x3x3 case due to the existence of interference in overlapping regions. But, the interference is lower compared to 1x3x1 case because of the reduction of interference from neighboring cells.

PERFORMANCE METRIC (FULL BUFFER, PUSC, PF, SISO)	**1x3x1**	**3x3x1**	**1x3x3**
THROUGHPUT (per user) (bps)	1125751.6	458570.8	538159.1
SECTORAL EFFICIENCY THROUGHPUT (per Sector) (bps/symbol)	3.554	4.343	5.096
GOODPUT (per user) (bps)	585007.3	245744.2	342403.2
SECTORAL EFFICIENCY GOODPUT (per Sector) (bps/symbol)	1.847	2.327	3.242
MAXIMUM GOODPUT of a User (bps)	4039200.0	739200.0	828960.0
PACKET ERROR RATE	0.155	0.161	0.120
AVERAGE PACKET DELAY (in case of retransmission)	12.2 (frames) 0.0611 (sec)	13.7 (frames) 0.0684 (sec)	18.8 (frames) 0.0942 (sec)

FREQUENCY REUSE MODES (1X2 SIMO)

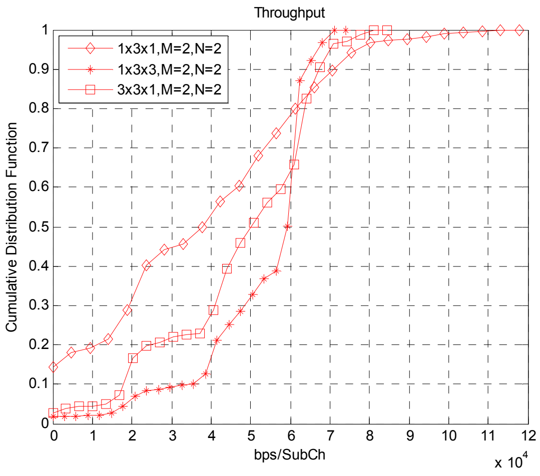


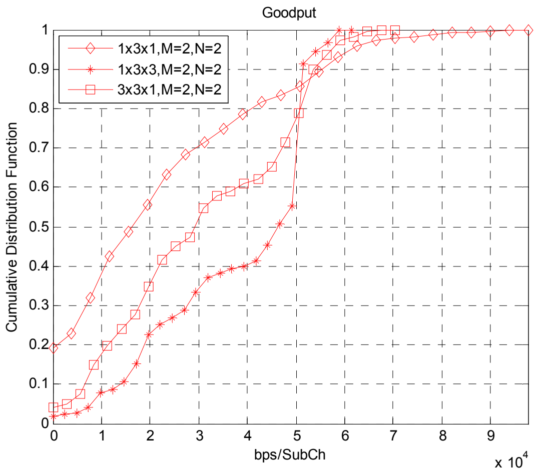


- When results have compared with SISO for the same frequecy resuse factor, there is;
    - Lower error rate than SISO due to higher antenna diversity
    - Better goodput performance due to lower repetition (lower retransmission of erroneous packets)

PERFORMANCE METRIC (FULL BUFFER, PUSC, PF, 1x2 SIMO)	**1x3x1**	**3x3x1**	**1x3x3**
THROUGHPUT (per user) (bps)	1236198.1	513640.6	567793.8
SECTORAL EFFICIENCY THROUGHPUT (per Sector) (bps/symbol)	3.902	4.864	5.377
GOODPUT (per user) (bps)	723071.0	321000.8	396817.2
SECTORAL EFFICIENCY GOODPUT (per Sector) (bps/symbol)	2.282	3.040	3.758
MAXIMUM GOODPUT of a User (bps)	3041280.0	727584.0	651552.0
PACKET ERROR RATE	0.101	0.105	0.067
AVERAGE PACKET DELAY (in case of retransmission)	13.2 (frames), 0.0660 (sec)	18.2 (frames), 0.0909 (sec)	18.5 (frames), 0.0927 (sec)

FREQUENCY REUSE MODES (2X2 MIMO)

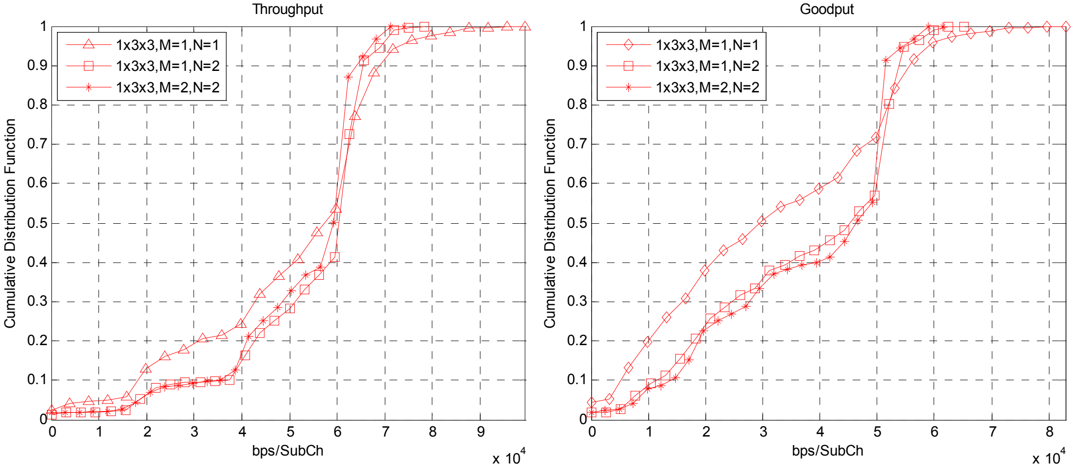




- When results have compared with SISO & SIMO for the same frequecy reuse factor, there is;
  - The lowest error rate due to the highest antenna diversity
  - The best goodput performance due to lowest repetition (lower retransmission of erroneous packets)

PERFORMANCE METRIC (FULL BUFFER, PUSC, PF, 2x2 MIMO)	1x3x1	3x3x1	1x3x3
THROUGHPUT (per user) (bps)	1221402.9	501323.6	550594.7
SECTORAL EFFICIENCY THROUGHPUT (per Sector) (bps/symbol)	3.855	4.747	5.214
GOODPUT (per user) (bps)	758146.9	334042.6	399620.0
SECTORAL EFFICIENCY GOODPUT (per Sector) (bps/symbol)	2.393	3.163	3.784
MAXIMUM GOODPUT of a User (bps)	2930400.0	703296.0	614064.0
PACKET ERROR RATE	0.070	0.060	0.037
AVERAGE PACKET DELAY (in case of retransmission)	13.1 (frames), 0.0656 (sec)	18.8 (frames), 0.0940 (sec)	12.5 (frames), 0.0625 (sec)

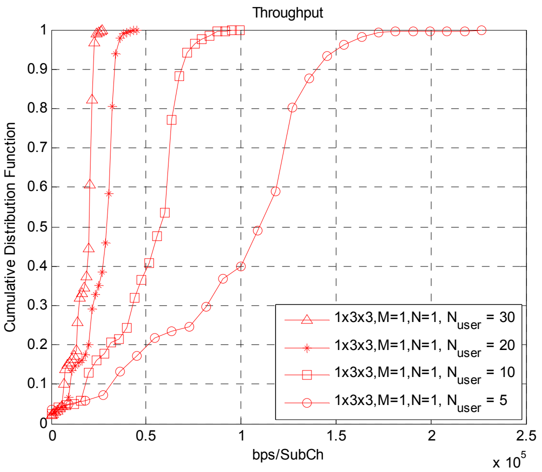
ANTENNA SCHEME (REUSE: 1X3X3)

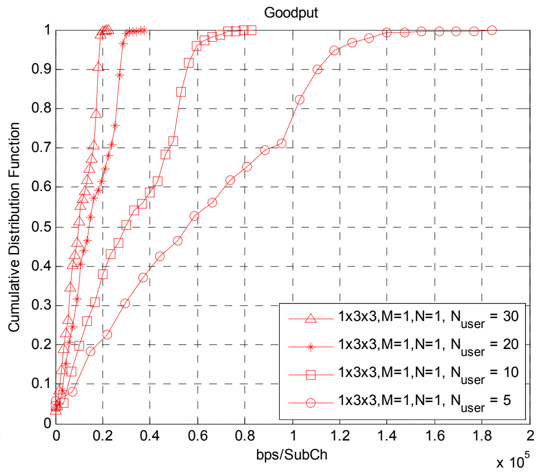


- As expected, the packet error rate decreases in case of increasing the number of antenna. (higher antenna divesity)
- Based on lower packet error rate, the goodput value increases .

PERFORMANCE METRIC (FULL BUFFER, PUSC, PF, Reuse:1x3x3)	SISO	1x2 SIMO	2x2 MIMO
THROUGHPUT (per user) (bps)	538159.1	567793.8	550594.7
SECTORAL EFFICIENCY THROUGHPUT (per Sector) (bps/symbol)	5.096	5.377	5.214
GOODPUT (per user) (bps)	342403.2	396817.2	399620.0
SECTORAL EFFICIENCY GOODPUT (per Sector) (bps/symbol)	3.242	3.758	3.784
MAXIMUM GOODPUT of a User (bps)	828960.0	651552.0	614064.0
PACKET ERROR RATE	0.120	0.067	0.037
AVERAGE PACKET DELAY (in case of retransmission)	18.8 (frames) 0.0942 (sec)	18.5 (frames) 0.0927 (sec)	12.5 (frames) 0.0625 (sec)

NUMBER OF USER (REUSE:1X3X3; SISO)

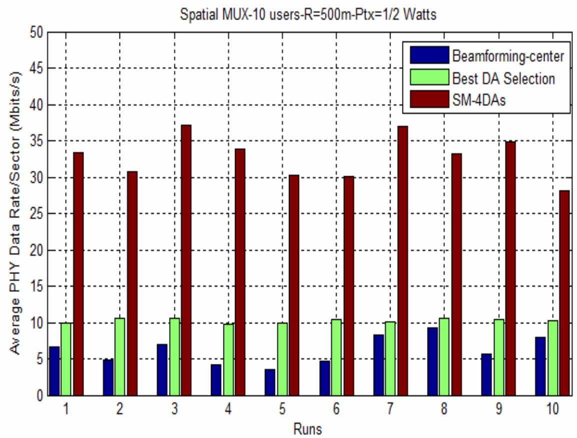


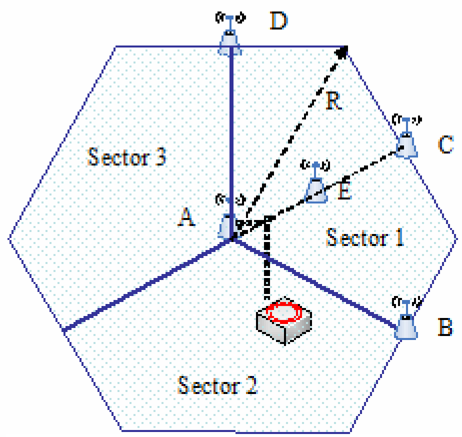


- The throughput and goodput per user decrease as the number of users per sector increases.
- The sectoral efficiencies are not affected significantly by the change in the number of users.
- Average packet delay in case of retransmission increases as the user density increases, since lower fraction of users can be scheduled.

PERFORMANCE METRIC (FULL BUFFER, PUSC, PF, 1x3x3, SISO)	NoU:5	NoU:10	NoU:20	NoU:30
THROUGHPUT (per user) (bps)	1050150.1	538159.1	272759.6	182149.3
SECTORAL EFFICIENCY THROUGHPUT (per Sector) (bps/symbol)	4.972	5.096	5.166	5.175
GOODPUT (per user) (bps)	66420.955	342403.2	166855.2	111656.0
SECTORAL EFFICIENCY GOODPUT (per Sector) (bps/symbol)	3.145	3.242	3.160	3.172
MAXIMUM GOODPUT of a User (bps)	1839763.2	828960.0	373824.0	225984.0
PACKET ERROR RATE	0.108	0.120	0.143	0.148
AVERAGE PACKET DELAY (in case of retransmission)	11.9 (frames), 0.0597 (sec)	18.8 (frames) 0.0942 (sec)	31.1 (frames) 0.1557 (sec)	40.6 (frames) 0.2031 (sec)

DISTRIBUTED MIMO (REUSE:1X3X3)





Parameter	Value
Site to Site Distance (m)	1000
Cell layout	3 sectors – FRF=3
Frequency Band (GHz)	3.5
Maximum number of remote BS at each sector	4
Number of BS array antenna elements	4
Number of mobile array antenna elements	4
Mobile Velocity (Km/h)	110
Channel Bandwidth (MHz)	10
Frame Duration (ms)	5
OFDM Symbol Duration (µs)	102.86
Number of Data Subcarriers	800
BS Transmit Power (mW)	500
Channel Profile	WINNER II C 2 Metropolitan
Mobile Station Distribution	Uniform, random positioning, 30 users per cell
Traffic Model	Full Buffer

•Virtual MIMO system operating in both LoS and NLoS conditions.
•Average throughput per sector covering10 users
•Simulated Schemes:
- Distributed MIMO (SM-4 DA Elements at points A,B,C,D)
- Best DA selection
- Single BS at the cell center (with beamforming)

•Significant improvement of Distributed MIMO over the other 2 schemes
•The proposed system efficiently reduce co-channel interference from neighboring cells and improves SINR leading to a great improvement of high speed users in terms of total throughput and fairness.

Optimal FFR for real time services-SISO

- Objective
  - Reduce the interference for the users at the cell border
  - Increase the system throughput
  - Find the best FFR factor and the radius of the interior cell region
- Strategy
  - Develop an optimization framework combining FFR and resource allocation
- Assumptions
  - Fast power control not used
  - Introduction of a Time sharing factor
- Linear optimization problem (Simplex method or primal dual interior point method)