Multi-Connectivity in 6G Mobile Networks by Space Division Multiplexing in Combination with Radio over Fiber

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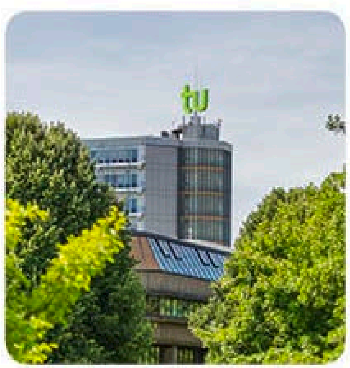
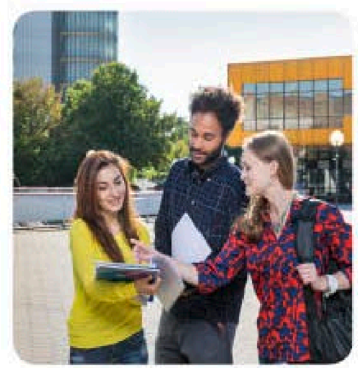




Outline

- Introduction, motivation
- Data rate scaling rules
- Capacity increase by space division multiplexing
- Radio over fiber with optical MIMO
- Proof of concept simulation results
- Summary and conclusions

Introduction

Evolution of the maximum data rate with mobile network generation and deployed carrier frequency ranges

Mobile network generation	**Maximum data rate**	**Carrier frequency ranges**
2G / GSM	256 kbit/s	0.9 … 1.0 GHz, 1.7 … 1.9 GHz
3G / UMTS	42 Mbit/s	1.9 … 2.2 GHz
4G / LTE	1 Gbit/s	0.8 … 0.9 GHz, 2.5 … 2.7 GHz
5G	10 Gbit/s	0.7 … 0.8 GHz, 3.4 … 3.8 GHz
6G	400 Gbit/s	tbd

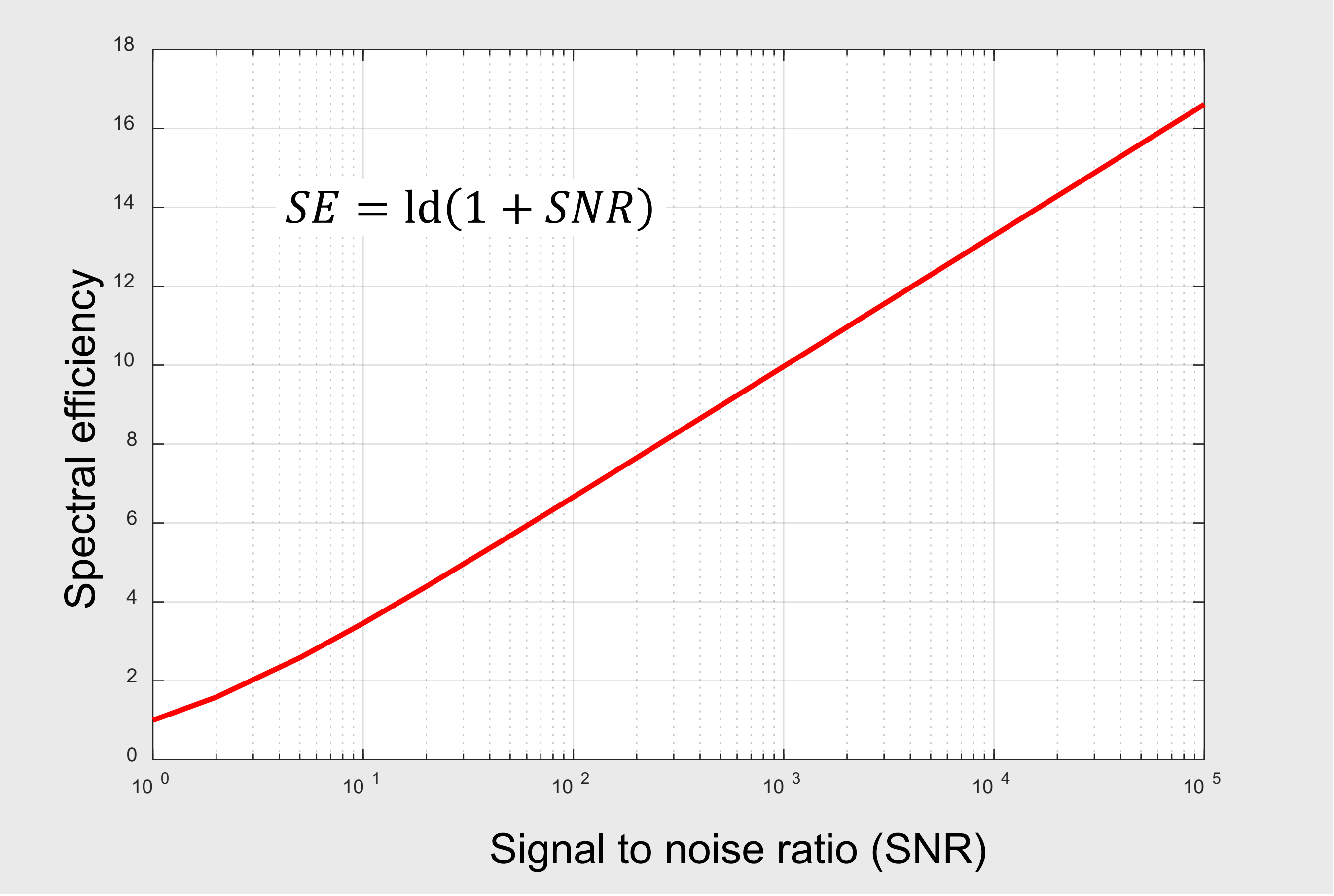
Increasing the data rate

data rate = symbol rate x number of bits per symbol

Number of bits
per time interval

Number of symbols
per time interval

Shannon capacity limit

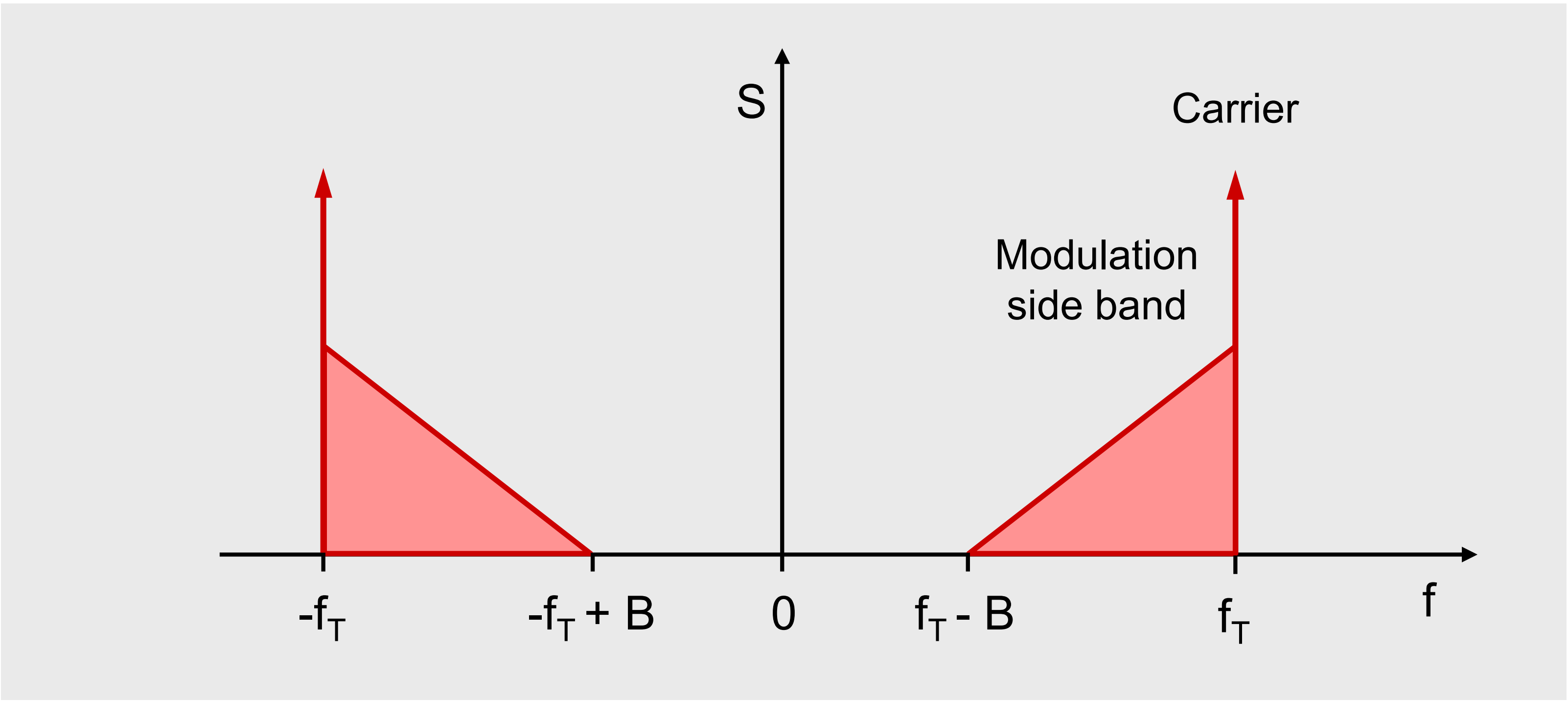


Symbol rate and bandwidth

Assumption: 10 bit per symbol

Data rate	Symbol rate	Bandwidth
100 Mbit/s	10 MBaud	10 MHz
1 Gbit/s	100 MBaud	100 MHz
10 Gbit/s	1 GBaud	1 GHz
100 Gbit/s	10 GBaud	10 GHz

Bandwidth and carrier frequency



Impedance matching and low loss power splitting can only be realized in a narrow frequency range

⇨ The carrier frequency has to be higher than the bandwidth by a factor 5 … 10

Symbol rate and bandwidth

Assumption: 10 bit per symbol

Data rate	Symbol rate	Bandwidth	Carrier frequency
100 Mbit/s	10 MBaud	10 MHz	100 MHz
1 Gbit/s	100 MBaud	100 MHz	1 GHz
10 Gbit/s	1 GBaud	1 GHz	10 GHz
100 Gbit/s	10 GBaud	10 GHz	100 GHz

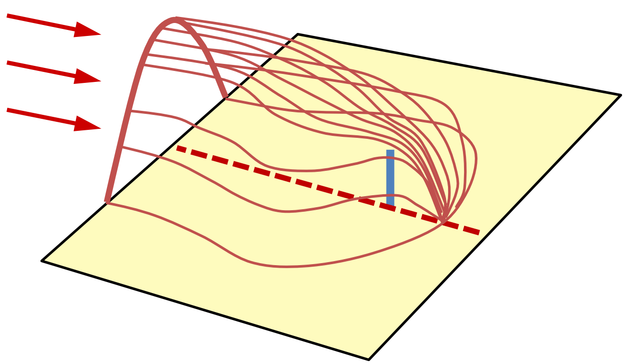
Received power

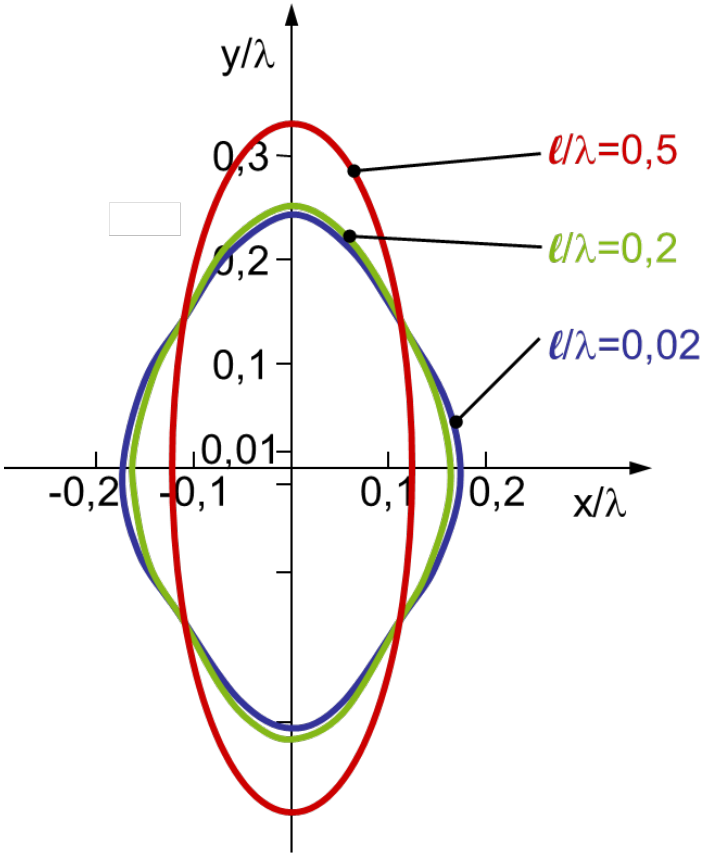
Power received by antenna $P_R = A_{eff}\ S$

Effective area

Power density

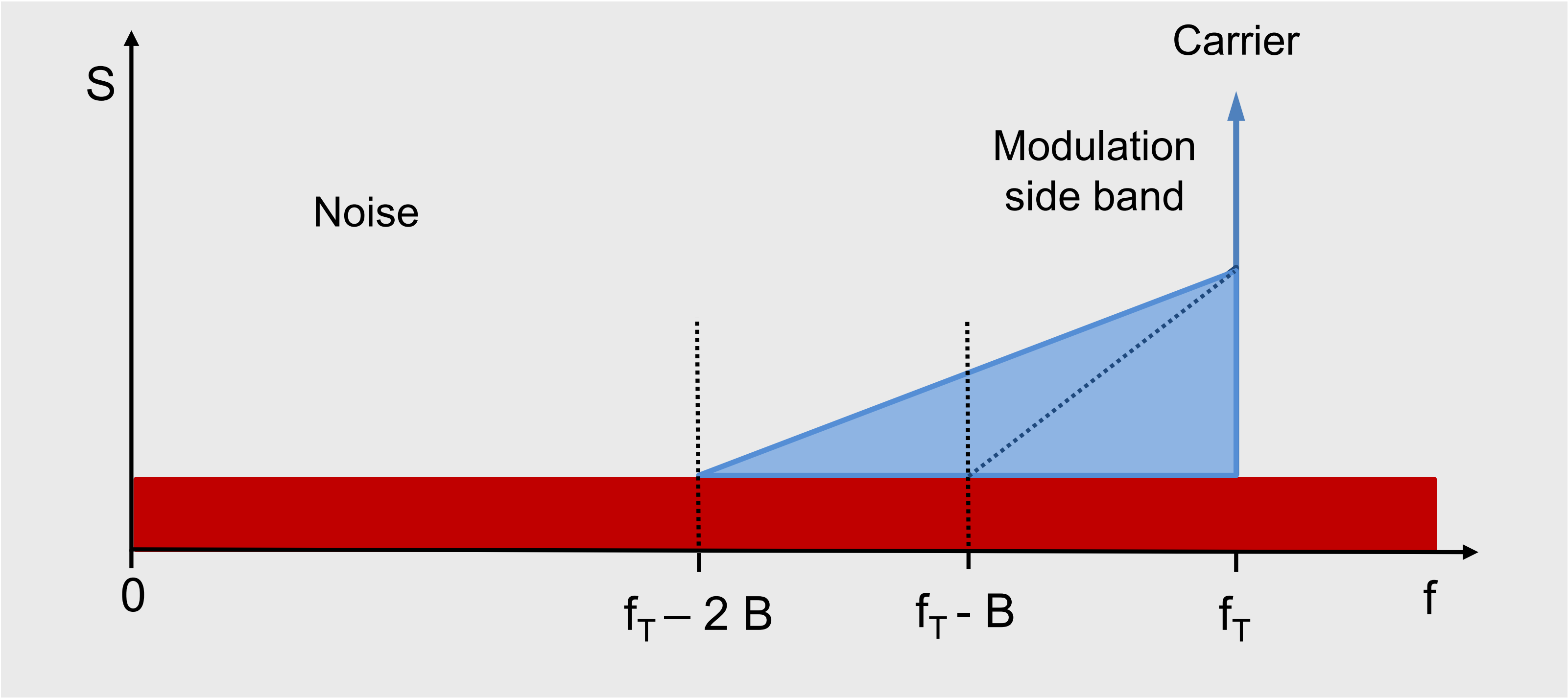
A_{eff}





Universal antenna rule
$$\frac{A_{eff}}{G} = \frac{\lambda^2}{4\,\pi}$$

Bandwidth and signal to noise ratio

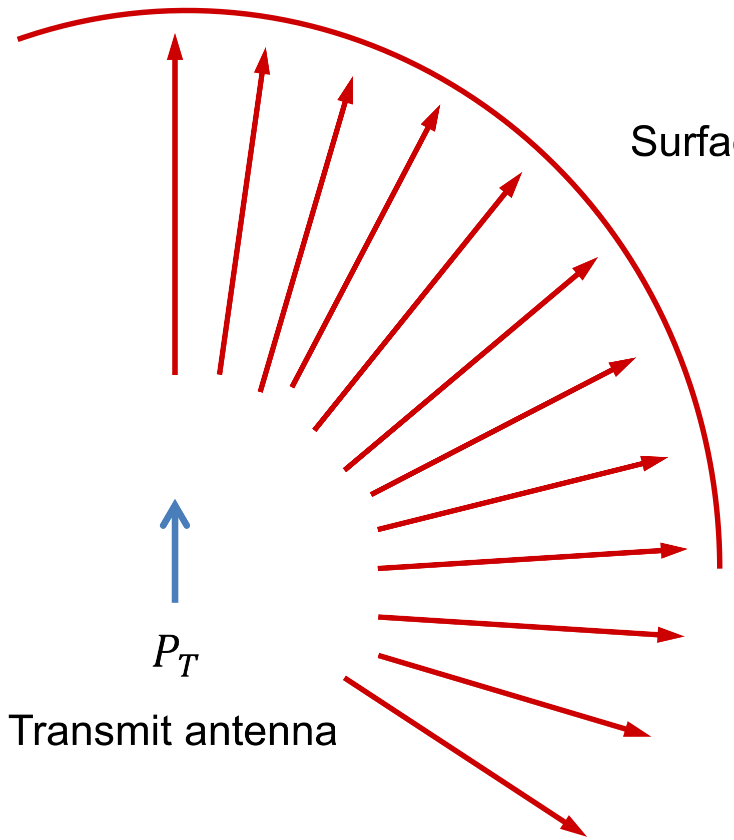


⇨ Doubling the bandwidth requires doubling the signal power to keep the signal to noise ratio constant

Scaling example – link power budget

				Factor
Data rate	1 Gbit/s	→	100 Gbit/s	100
Number of bits per symbol	10		10	1
Bandwidth	100 MHz	→	10 GHz	100
Carrier frequency	3 GHz	→	300 GHz	100
Effective area (same antenna type)	A_{eff}	→	A_{eff} / 10,000	1 / 10,000
Received power (same antenna type)	P_R	→	P_R / 10,000	1 / 10,000
Constant SNR	P_R	→	P_R x 100	100

Coping with received power



Surface of a sphere $A = 4\,\pi\,r^2$

Power density $S = \dfrac{P_T}{4\,\pi\,r^2}$

Scaling example

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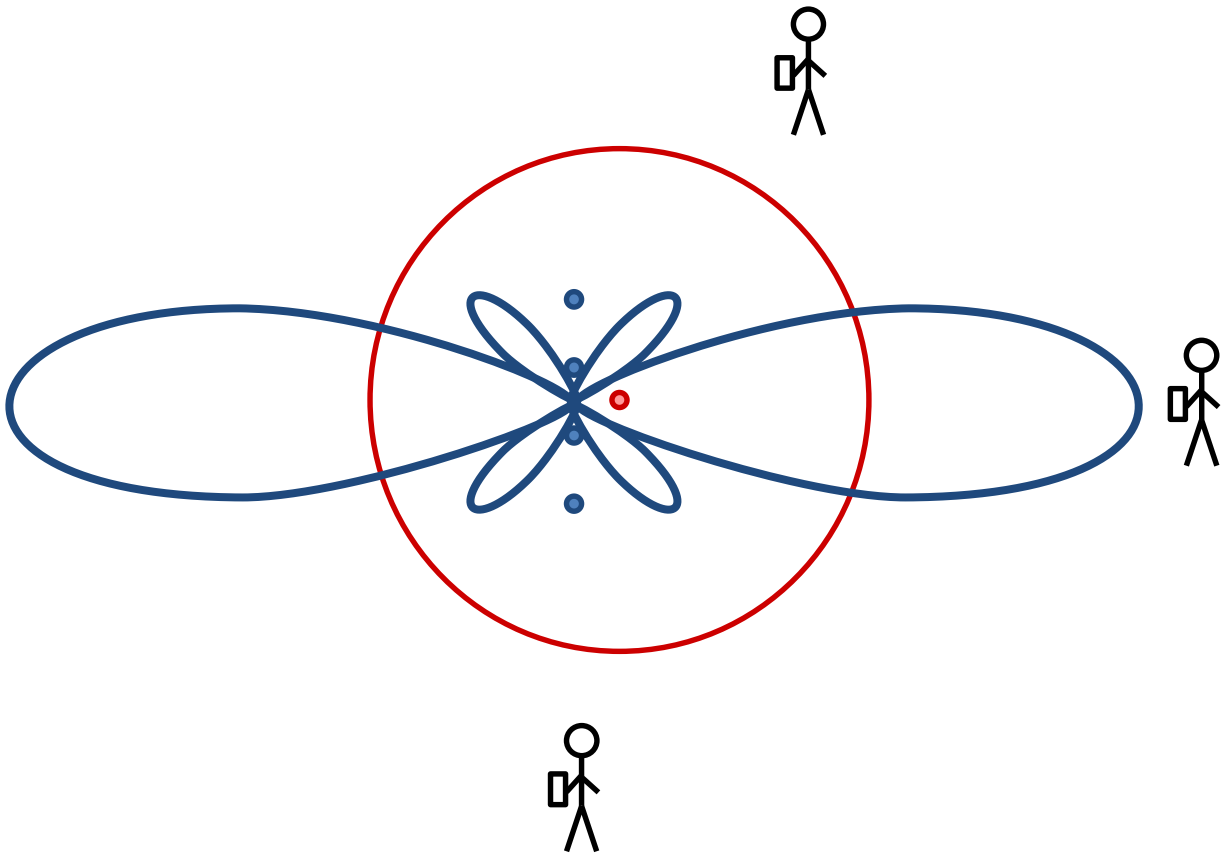
Received power (same antenna type)	P_R	→	P_R / 10,000	1 / 10,000
Constant SNR	P_R	→	P_R x 100	100
Cell radius	500 m	→	0.5 m	1 / 1,000

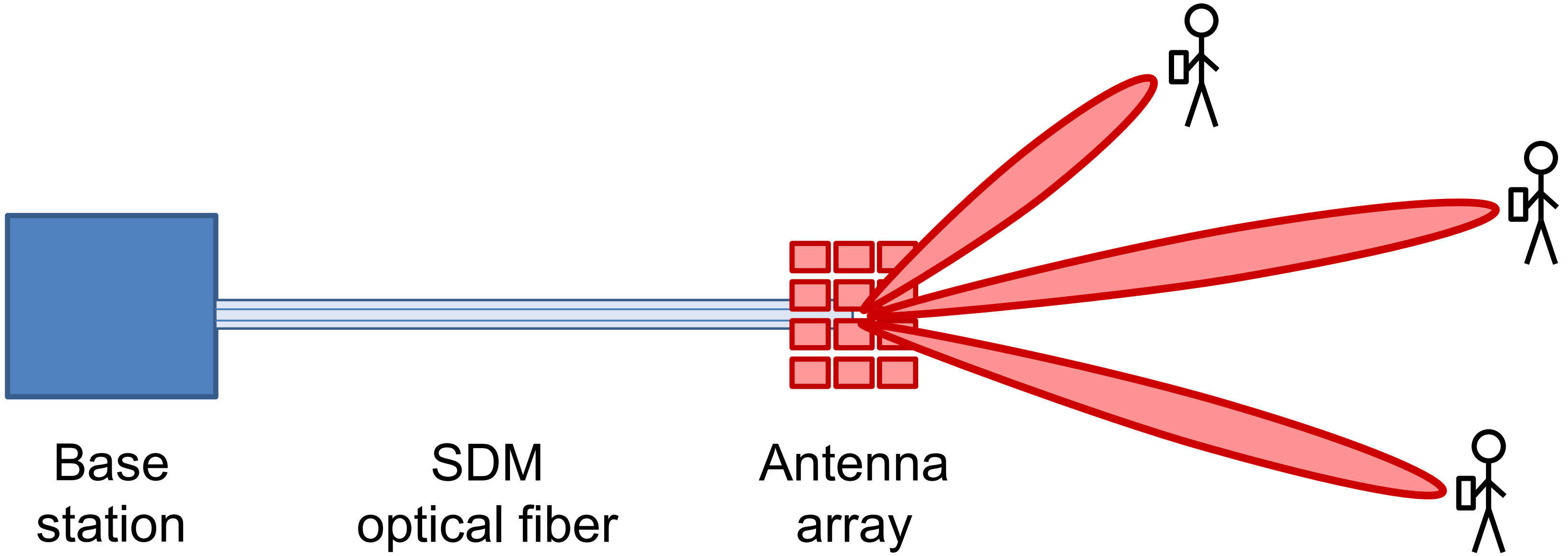
Scaling example

				Factor
Data rate	1 Gbit/s	→	100 Gbit/s	100
Number of bits per symbol	10		10	1
Bandwidth	100 MHz	→	10 GHz	100
Carrier frequency	3 GHz	→	300 GHz	100
Effective area (same antenna type)	A_{eff}	→	A_{eff} / 10,000	1 / 10,000
Received power (same antenna type)	P_R	→	P_R / 10,000	1 / 10,000
Constant SNR	P_R	→	P_R x 100	100
Cell radius	500 m	→	50 m	1 / 10
Antenna gain	2	→	20,000	10,000

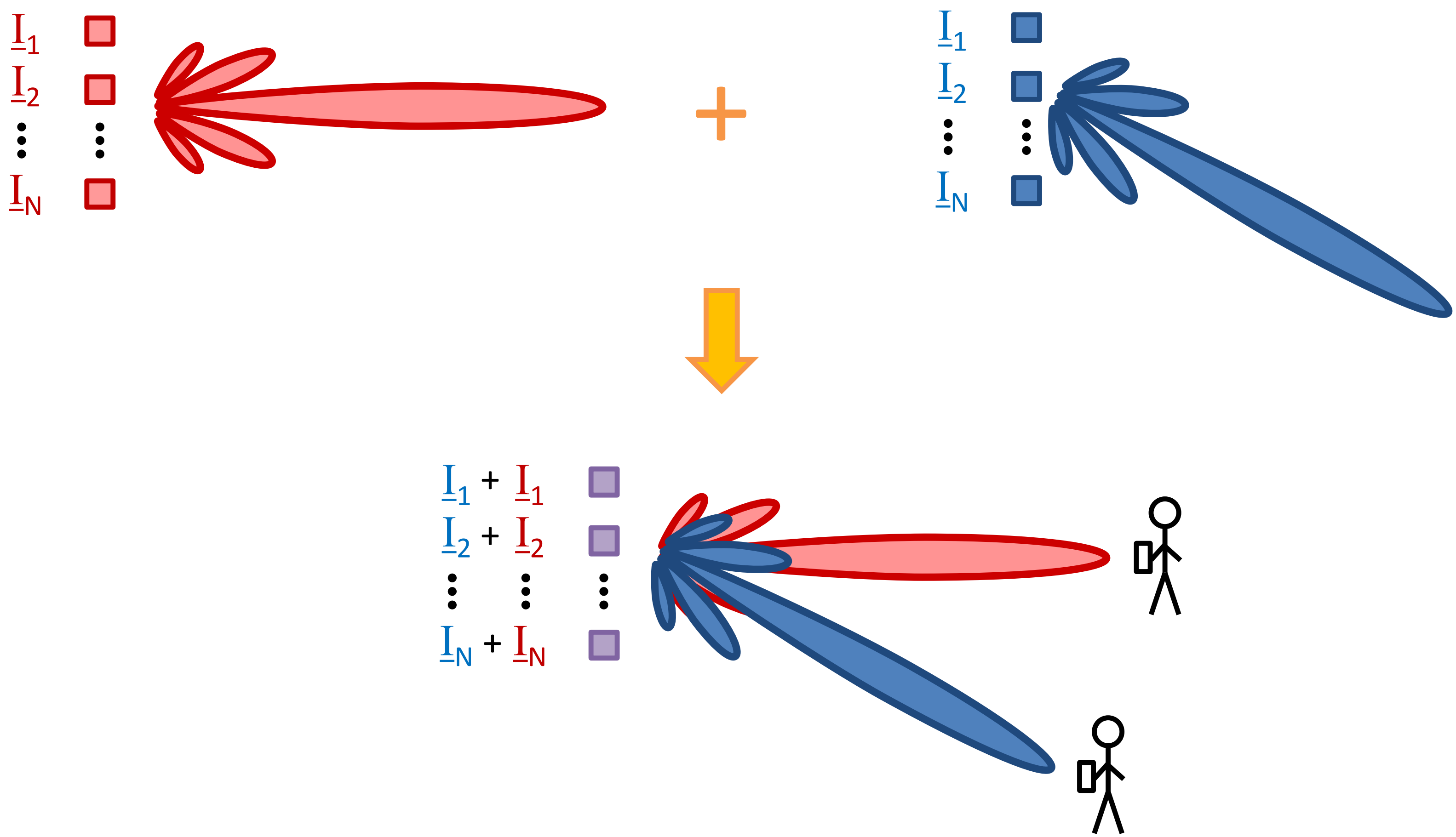
Antenna gain and directivity



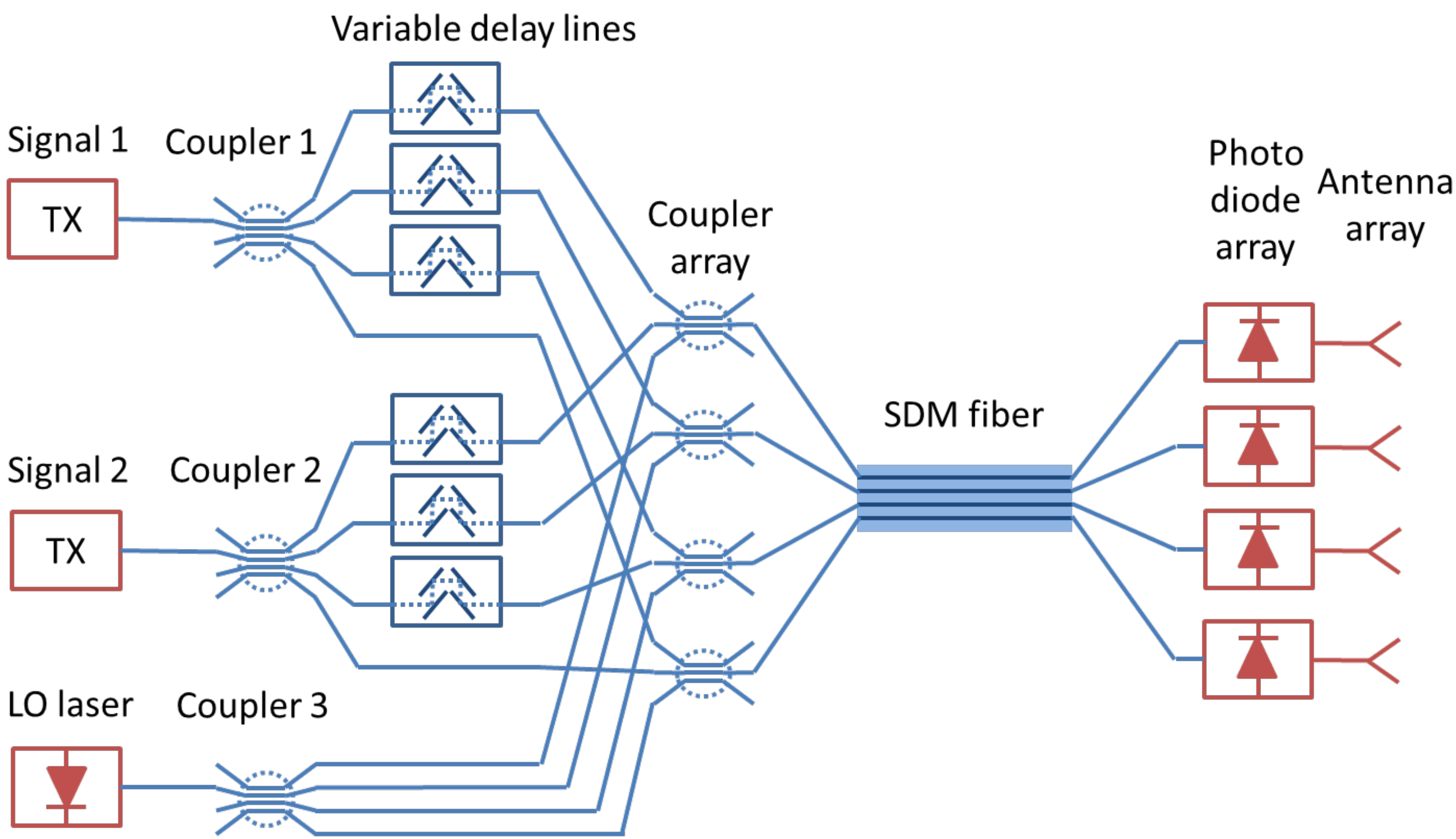
Capacity increase by SDM with RoF



Serving multiple users by superposition of signals

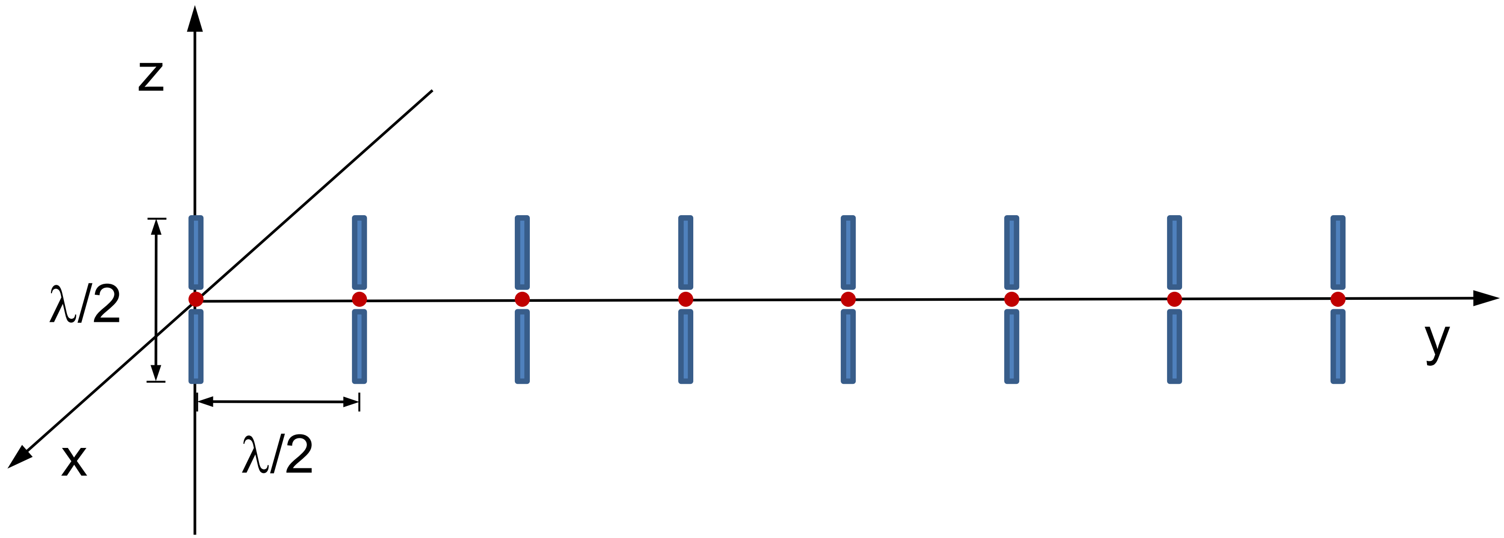


Signal generation by optical MIMO

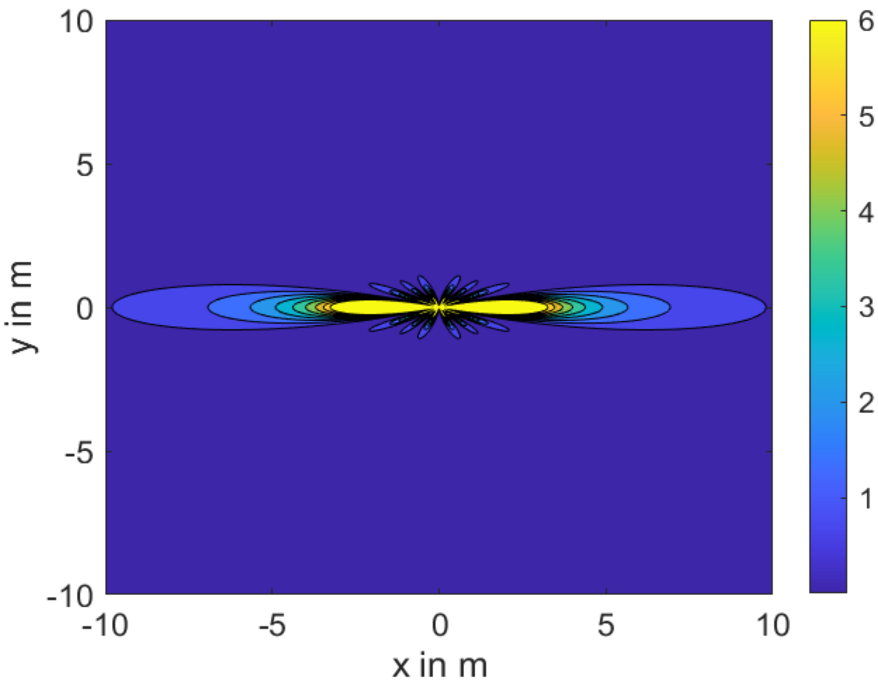


Set-up for proof of concept simulations

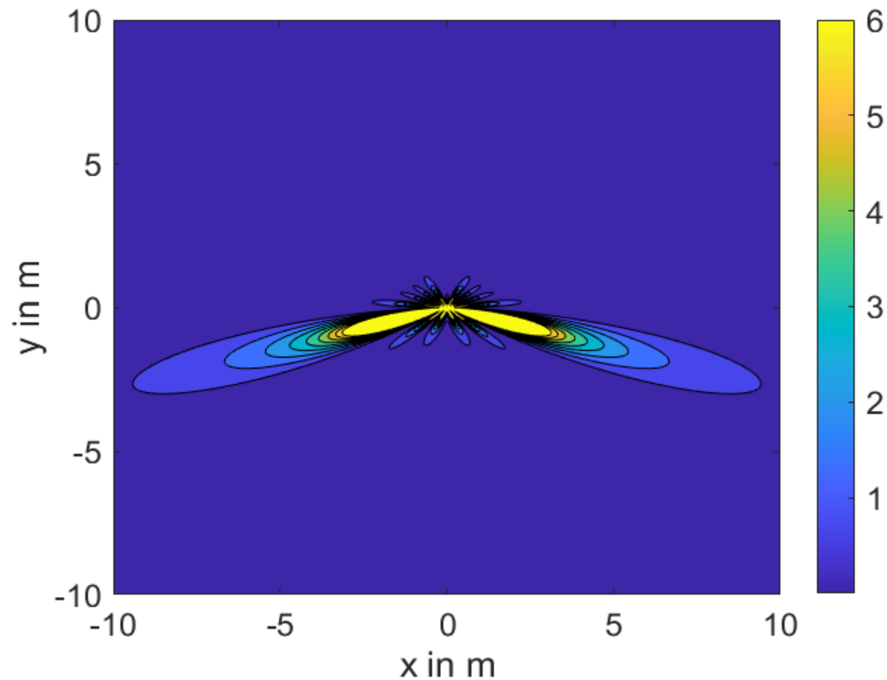
Generic antenna configuration: array with eight $\lambda/2$ dipoles



Signals for user 1 and user 2

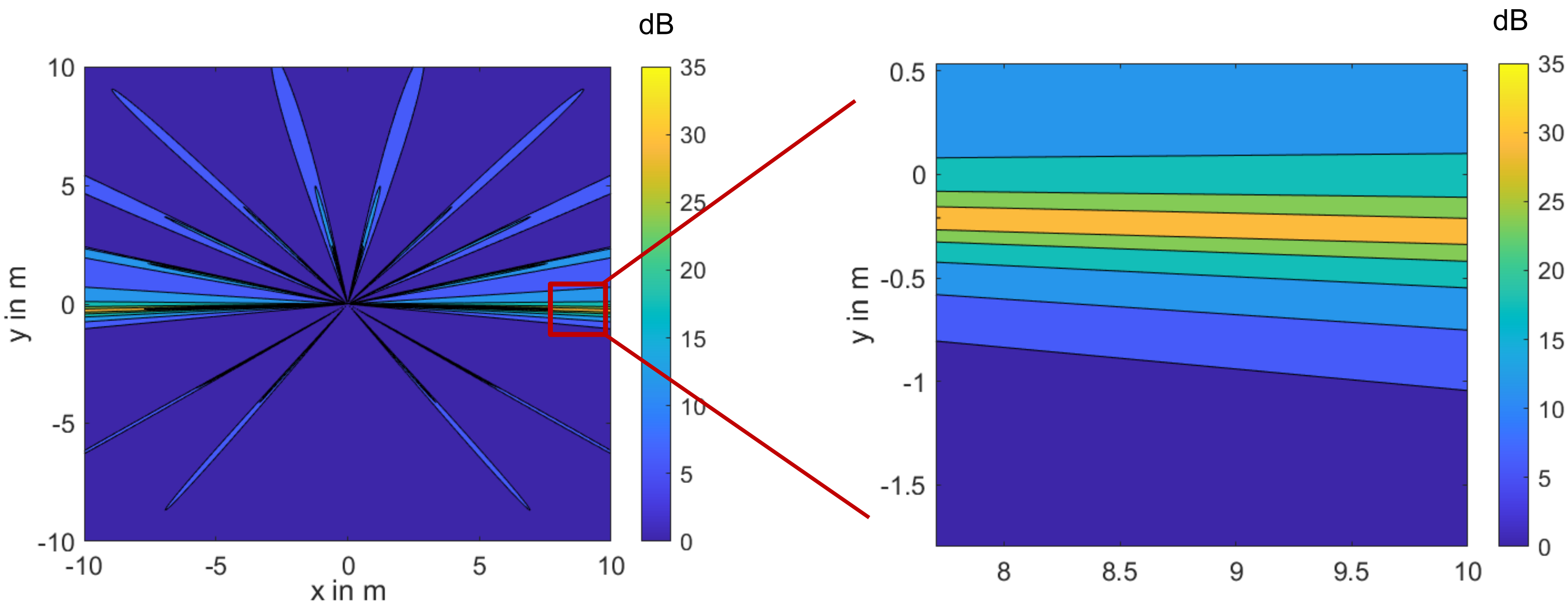


Normalized signal power density of signal 1

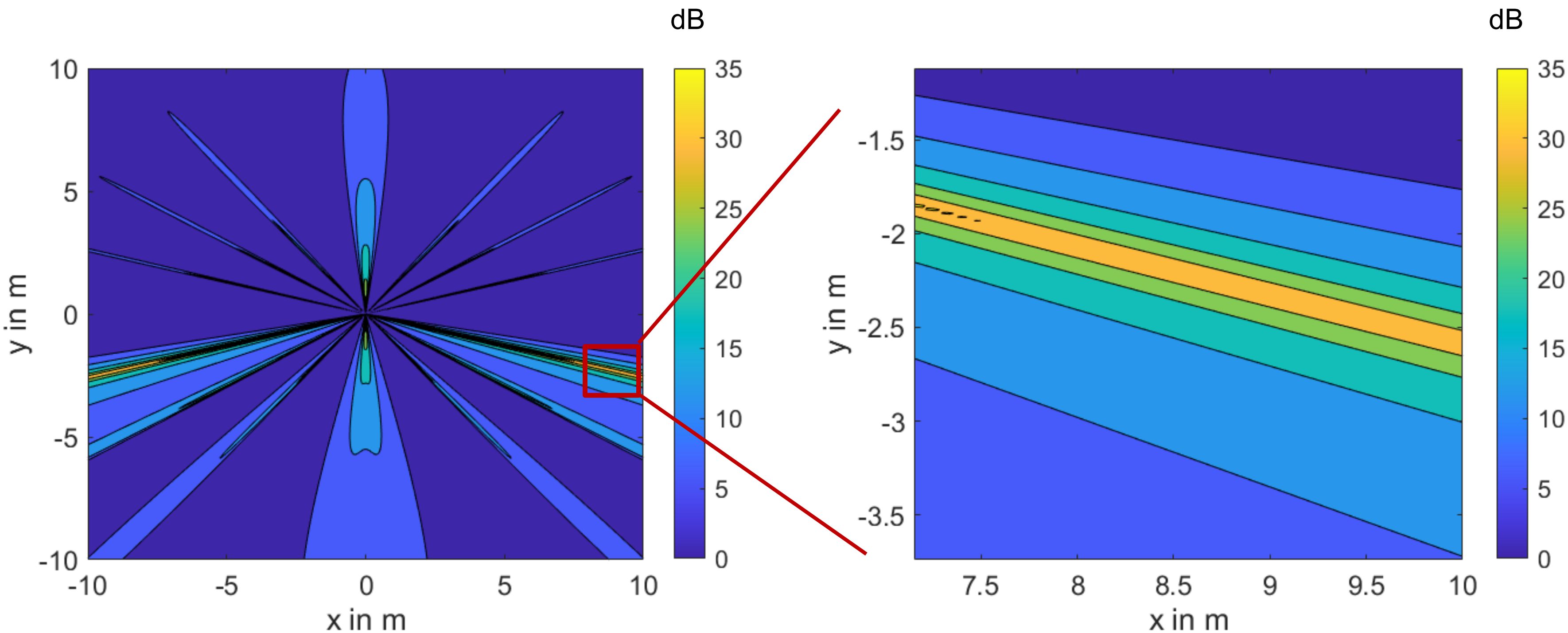


Normalized signal power density of signal 2

SNR for user 1



SNR for user 2



Summary and conclusions

- Mobile networks with data rates > 100 Gbit/s need carrier frequencies > 100 GHz
- Viable link budgets can only be realized with antennas with high gain / directivity
- The high directivity can be leveraged to increase capacity by space division multiplexing
- We have proposed an energy efficient optical MIMO implementation in combination with radio over fiber
- Proof of concept simulation results demonstrate the feasibility of the concept

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