Multipath propagation effects in LTE:

impact on Channel Estimation and a potential solution

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Topics to discuss

- History of mobile communication
- What is OFDMA?
- What is Multipath Propagation Channel?
- What is Channel Estimation?
- Challenges of Channel Estimation
- Comparison of Estimated Channel and Actual Channel

- Our motivation
- Conclusion

Introduction to LTE (4G)

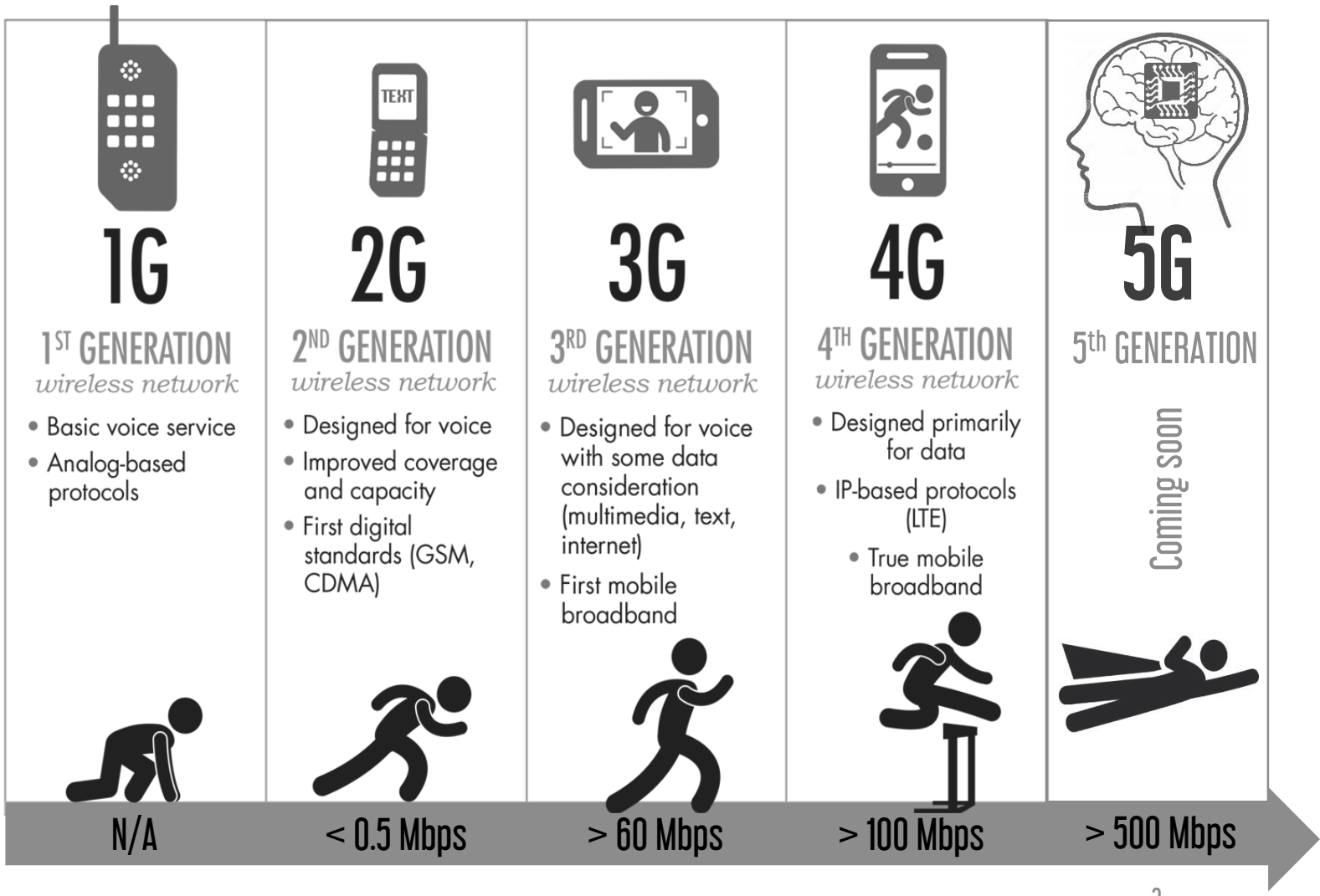
Key technologies of 4G

LTE utilizes **OFDMA** and **MIMO**

LTE – Long Term Evolution

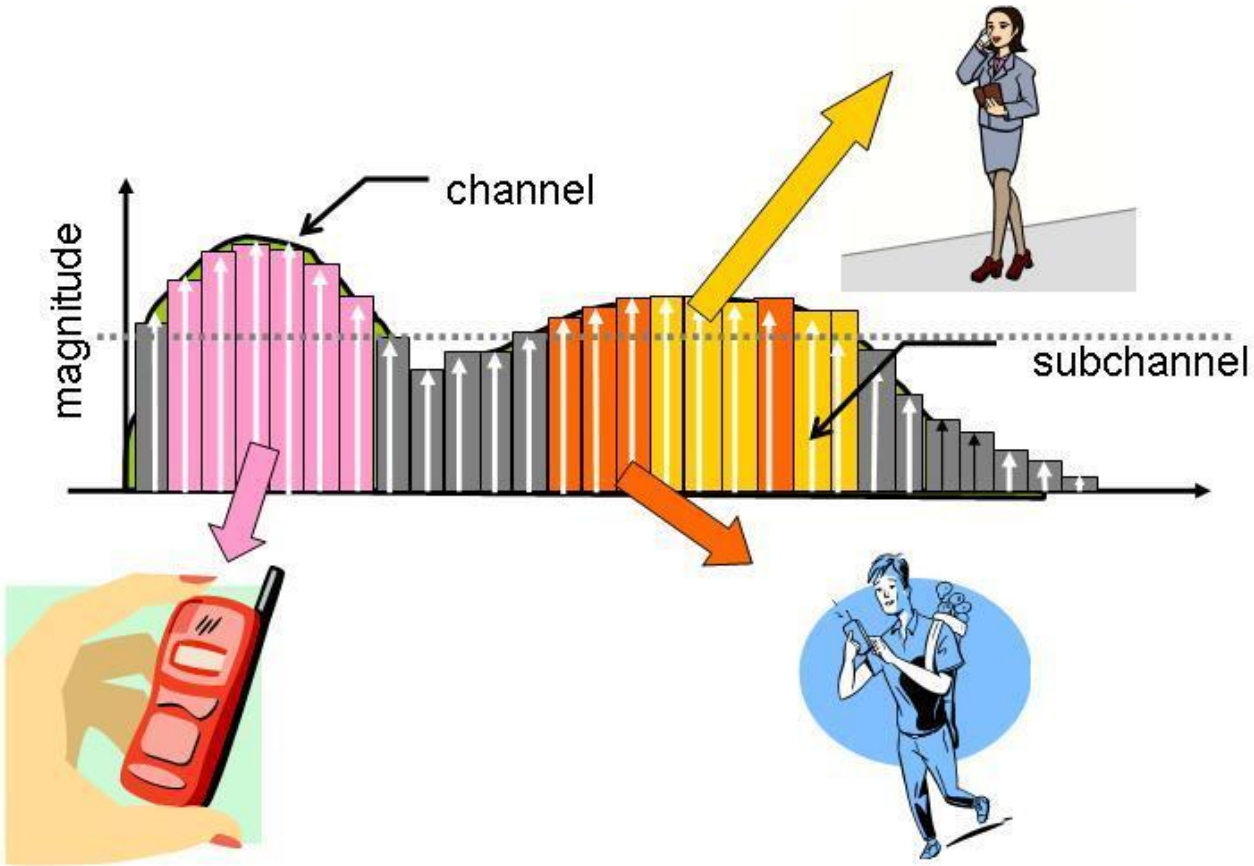
OFDMA – Orthogonal Frequency-Division Multiple Access

MIMO – Multiple Input and Multiple Output, multi-antennae system

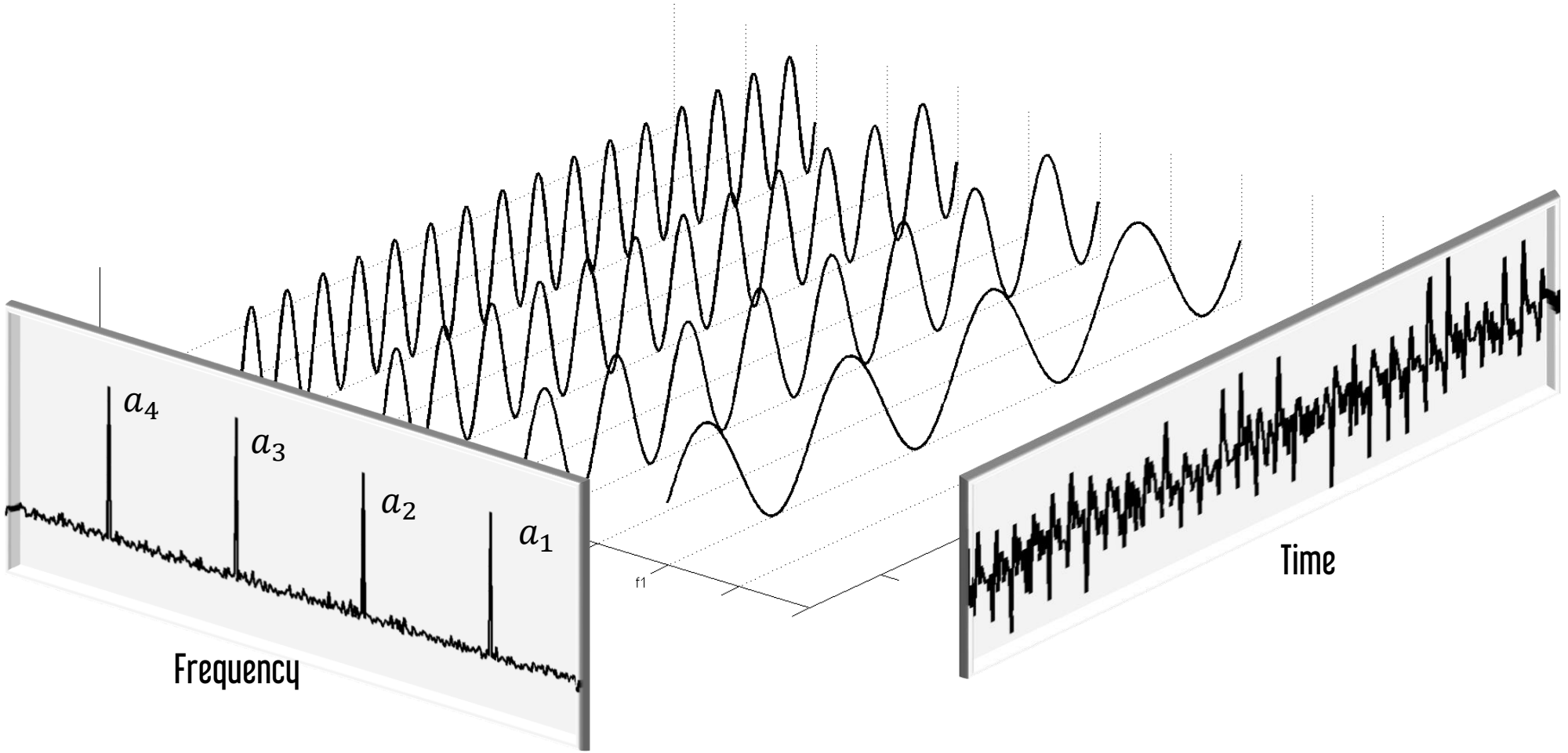


What is OFDMA?

- Flexible radio resource allocation for users
- Instead of increasing data sampling rate, OFDMA uses several orthogonal waveforms to transmit data
- Subchannels are orthogonal to each other, there is no interference between them

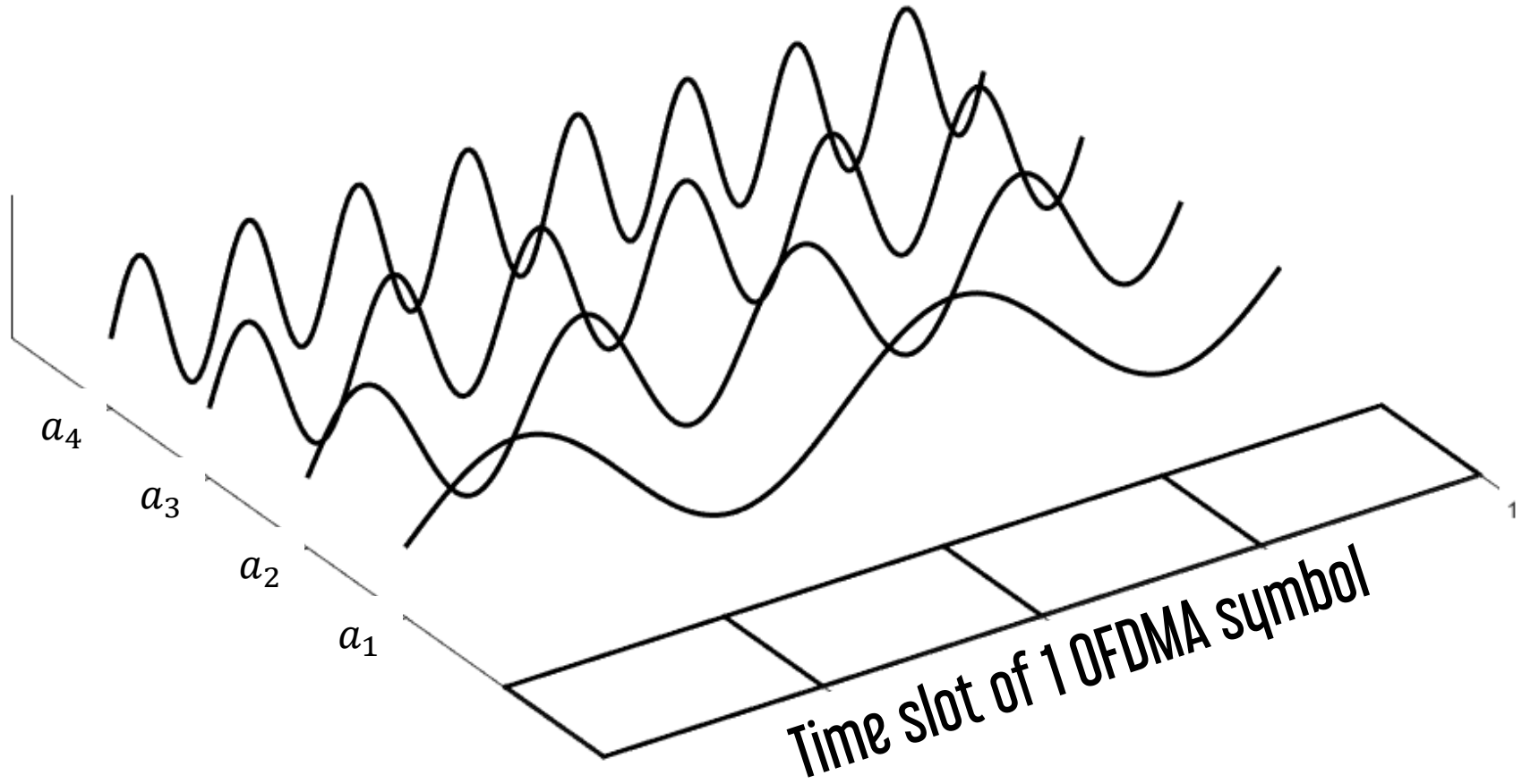


Time-frequency representation of OFDMA principles



Orthogonal channels (subcarriers) can be shared among up to four users, or can be used by one user. Flexible approach for resource allocating

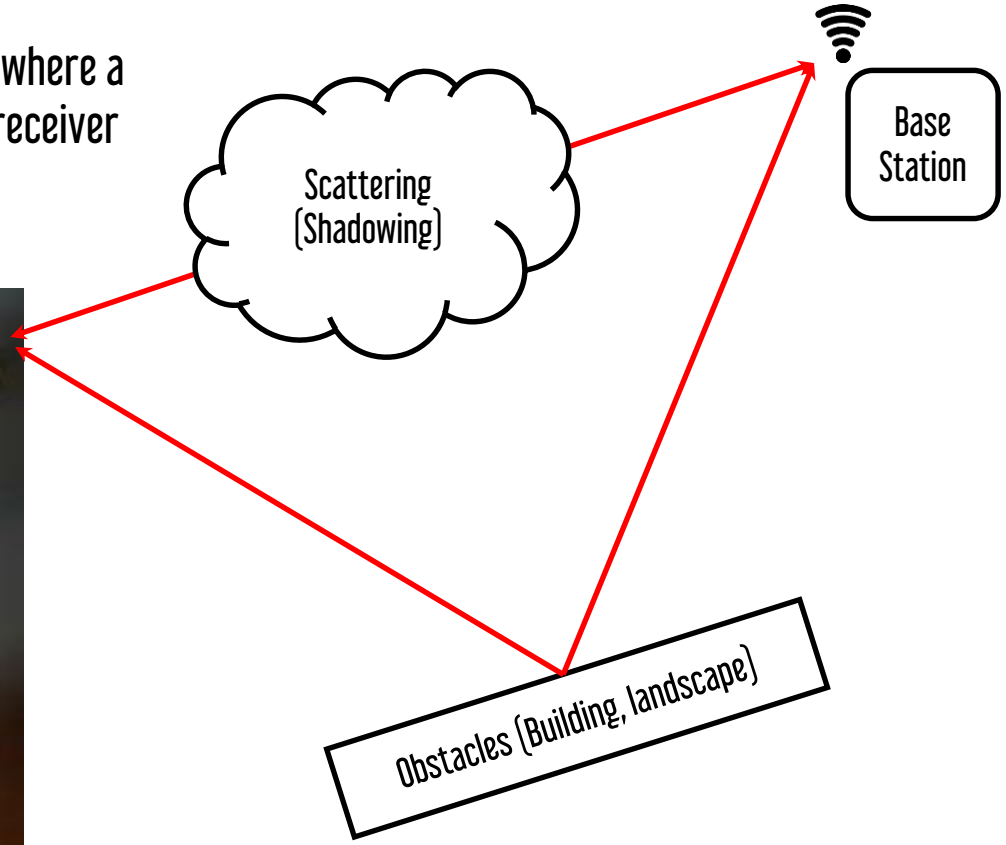
No need to increase sampling rate



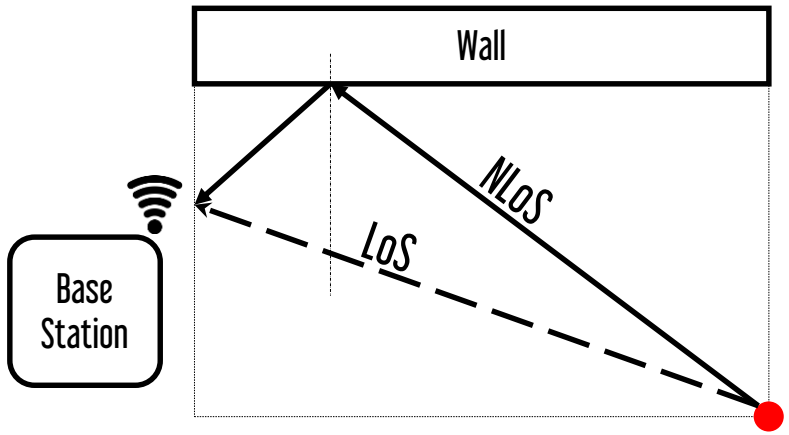
Instead of increasing sampling rate, OFDMA allows us to utilize orthogonal subcarriers and at the same time does not decrease sampling time slot

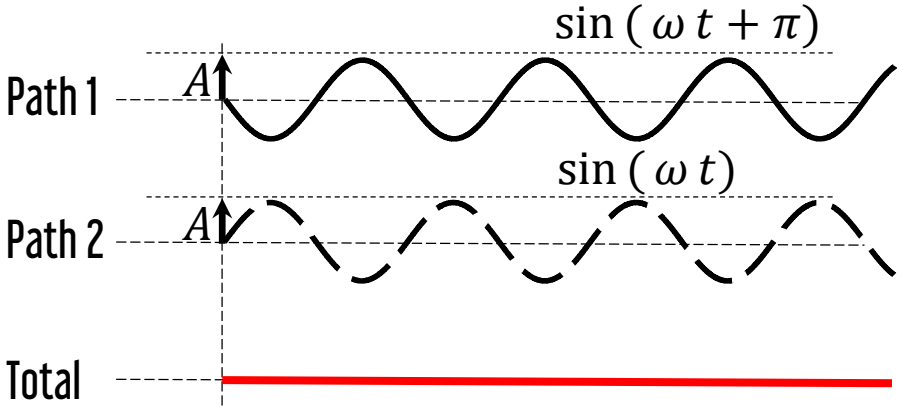
What is Multipath Propagation Channel?

Multipath effects occur in a wireless channel, which is called Multipath channel, where a transmitted signal reflects from different obstacles. Instead of one signal, the receiver receives several copies of the transmitted signal.



Video Call is loading channel in both sides
High network capacity must be performed in both sides





If the signals come in opposite phases, they can give almost zero in sum

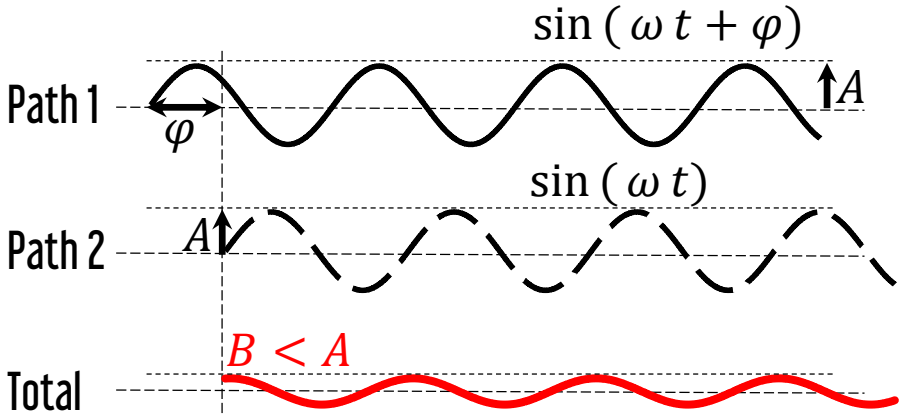
$$s(t) = 0$$

D_{NLoS} - the length of the NLoS path
D_{LoS} - the length of the LoS path

$$s(t) = s(t) + s(t + \tau)$$

$$\tau = \frac{D_{NLoS} - D_{LoS}}{c}$$

$$\varphi = \omega \cdot \tau$$



If the signals come in different phases, they can give hugely attenuated signal in sum

$$s(t) = B \sin (\omega t + \psi)$$

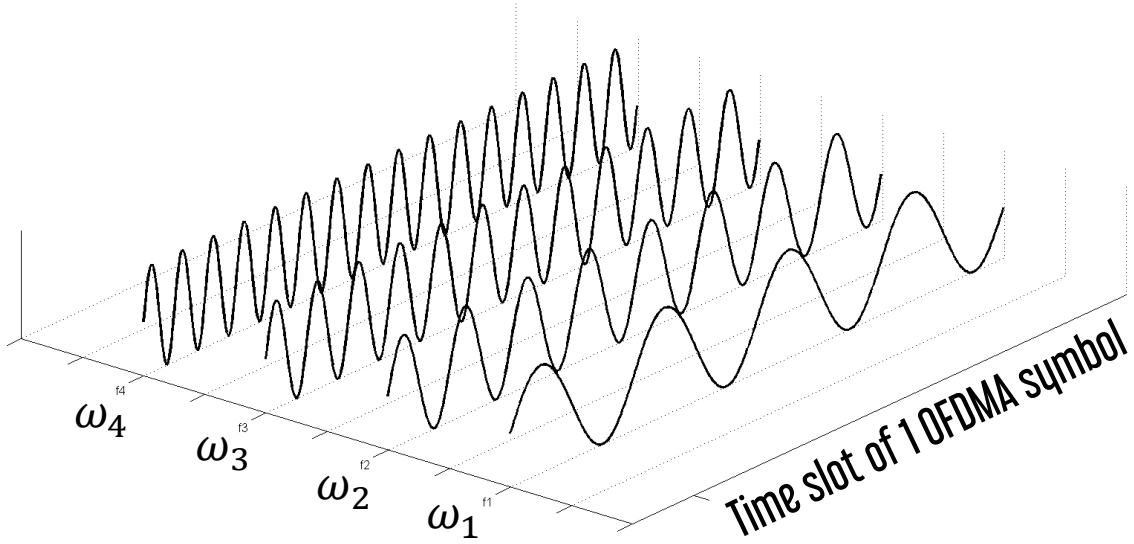
The dramatic attenuation of the received signals is called as Deep Fading Effect. The most harmful effect of the multipath propagation.

Multipath and OFDMA

Time delay between LoS and NLoS
$\tau = 10^{-6}$ sec ~ 300 m

$\Delta f = \frac{\pi}{3} \cdot 10^6$ Hz ~ 1047197 Hz

$\omega_1 = 1 \cdot \Delta f, \quad s_1(t) = \sin(\omega_1 t)$
$\omega_2 = 2 \cdot \Delta f, \quad s_2(t) = \sin(\omega_2 t)$
$\omega_3 = 3 \cdot \Delta f, \quad s_3(t) = \sin(\omega_3 t)$
$\omega_4 = 4 \cdot \Delta f, \quad s_4(t) = \sin(\omega_4 t)$



$s(t) = s(t) + s(t+\tau)$

$\omega_3 t + \omega_3 \tau = \omega_3 t + \pi\, 10^6 \cdot 10^{-6} = \omega_3 t + \pi$

$\omega_1 = \frac{\pi}{3} 10^6$
$\omega_2 = \frac{2\pi}{3} 10^6$
$\omega_3 = \pi\, 10^6$
$\omega_4 = \frac{4\pi}{3} 10^6$

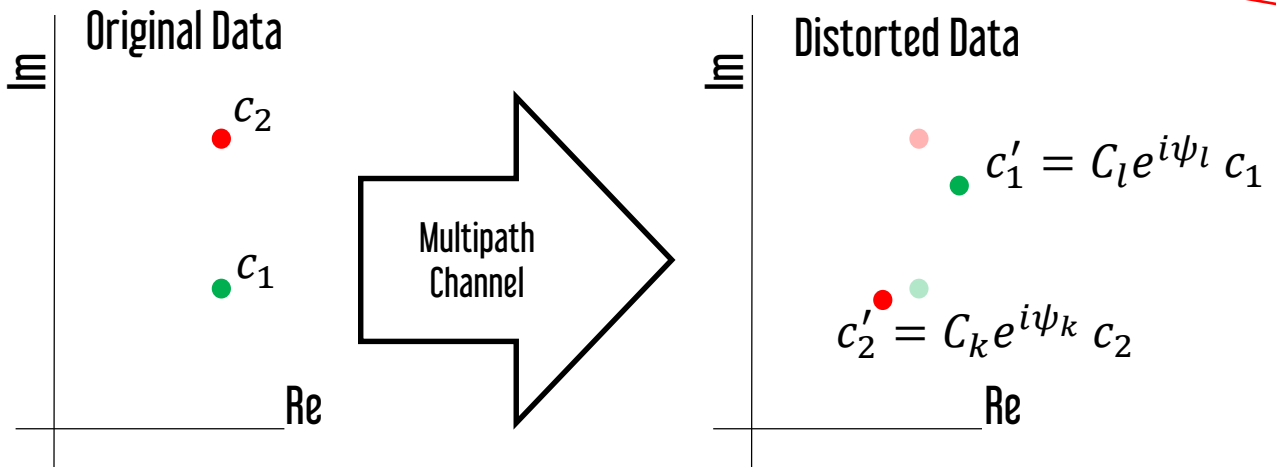
$\sin(\omega_1 t) + \sin(\omega_1 t + \omega_1 \tau) = B_1 \sin(\omega_1 t + \psi_1)$
$\sin(\omega_2 t) + \sin(\omega_2 t + \omega_2 \tau) = B_2 \sin(\omega_2 t + \psi_2)$
$\sin(\omega_3 t) + \sin(\omega_3 t + \omega_3 \tau) = \sin(\omega_3 t) - \sin(\omega_3 t) = 0$
$\sin(\omega_4 t) + \sin(\omega_4 t + \omega_4 \tau) = B_4 \sin(\omega_4 t + \psi_4)$

Multipath channel becomes frequency selective in OFDMA

Some interesting questions

ω_1: $\sin(\omega_1 t) + \sin(\omega_1 t + \omega_1 \tau) = B_1 \sin(\omega_1 t + \psi_1)$
ω_2: $\sin(\omega_2 t) + \sin(\omega_2 t + \omega_2 \tau) = B_2 \sin(\omega_2 t + \psi_2)$
ω_3: $\sin(\omega_3 t) + \sin(\omega_3 t + \omega_3 \tau) = B_3 \sin(\omega_3 t + \psi_3)$
ω_4: $\sin(\omega_4 t) + \sin(\omega_4 t + \omega_4 \tau) = B_4 \sin(\omega_4 t + \psi_4)$

ω_k: $C_k \cdot e^{i(\omega_k t + \psi_k)} = C_k\, e^{i\psi_k} \cdot e^{i\omega_k t}$



Training sequences (TS) are used in LTE in order to estimate distortion coefficients

How can we estimate attenuation coefficients B_1, B_2, B_3, B_4 and phases $\psi_1, \psi_2, \psi_3, \psi_4$.

If we know sent Data, we can estimate channel distortion coefficients. This procedure is called as **Channel estimation** (CE) procedure in LTE.

$$CE_k = \frac{c_k'}{c_k}$$

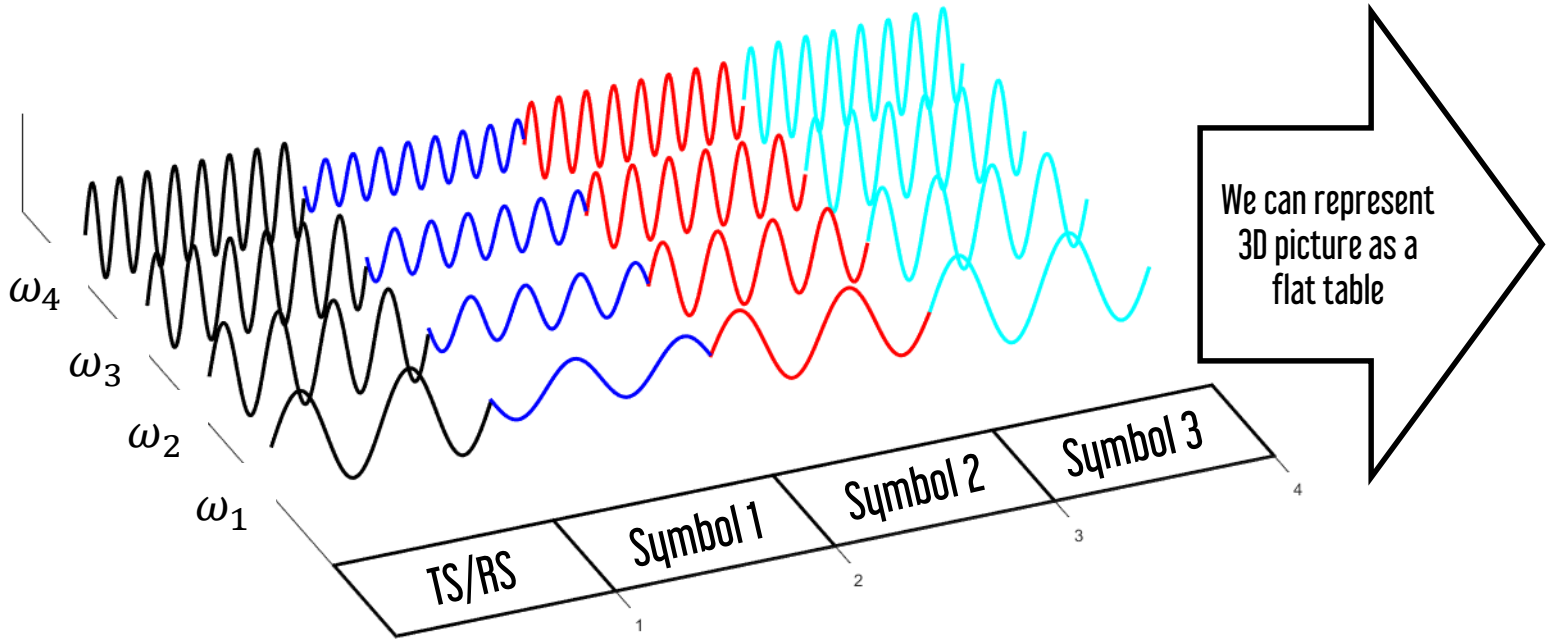
Reconstruction of distorted data can be done as follows:

Received data D_k' through the channel k must be divided on estimated distortion coefficient CE_k:

$$\widetilde{D}_k = \frac{D_k'}{CE_k}$$

The reconstruction of distorted data is called as **Equalization** procedure

How to send training sequence in OFDMA



We can represent 3D picture as a flat table

Reference Symbol	Symbol 1	Symbol 2	Symbol 3
RS1	a_1	a_5	a_9
RS2	a_2	a_6	a_{10}
RS3	a_3	a_7	a_{11}
RS3	a_4	a_8	a_{12}

In LTE, such kind of table representation of Data is called as Resource Block

We can put TS (or Reference Symbols (RS) in LTE) somewhere in known position in the signal.
Using RS we can perform Channel Estimation

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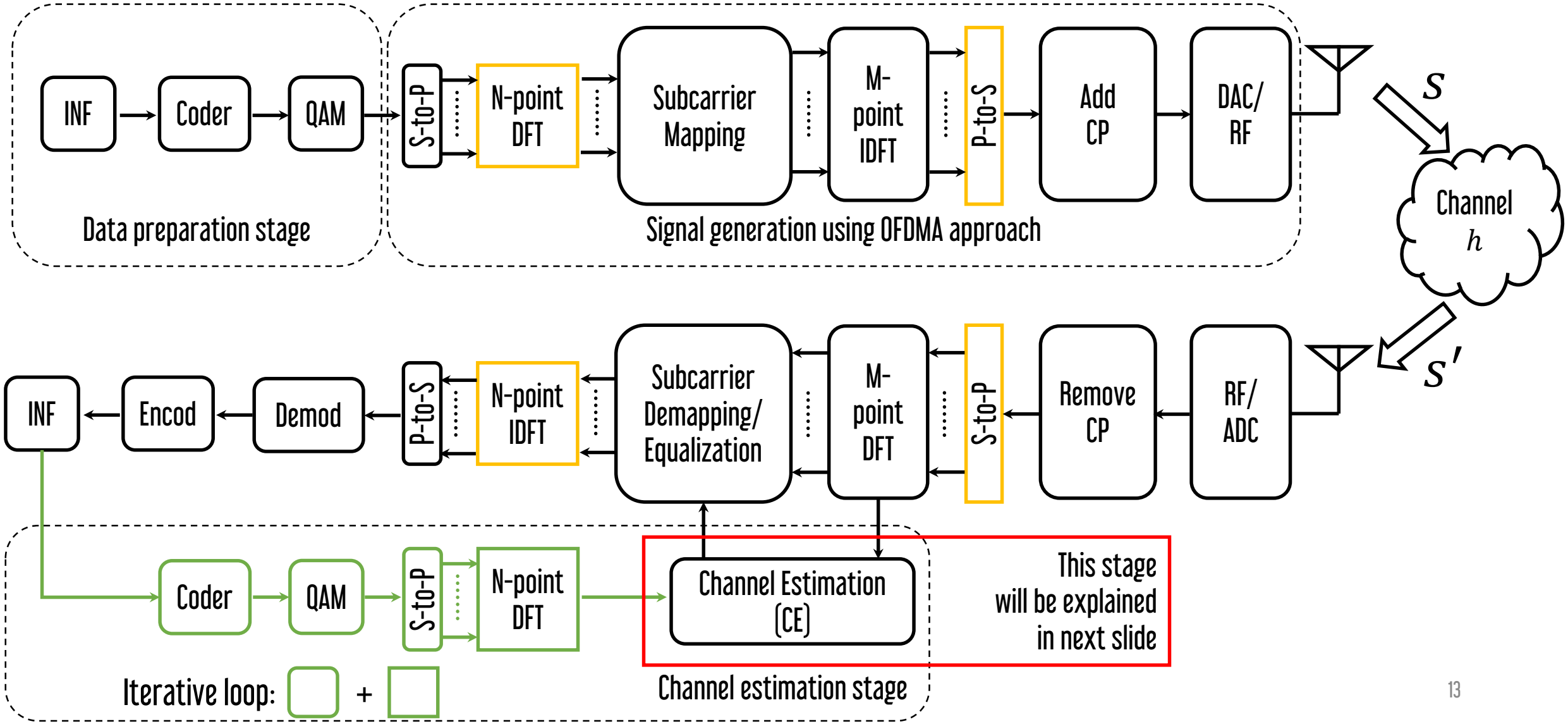
Communication process in LTE

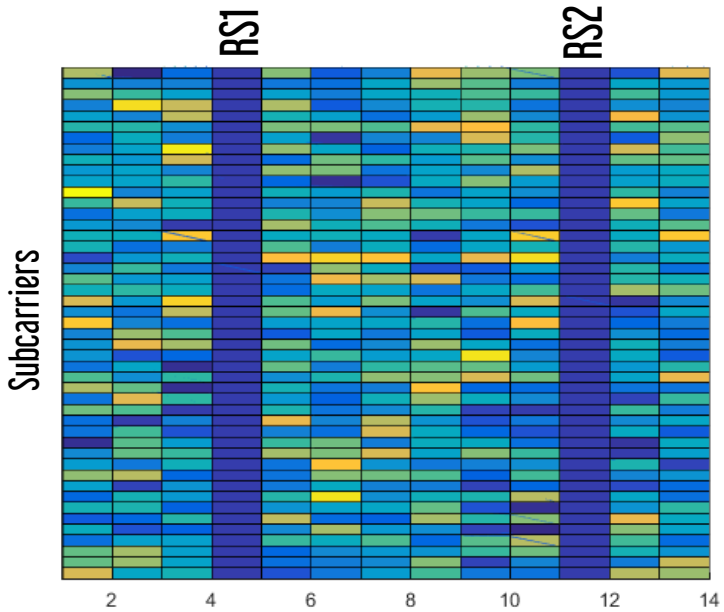


Channel estimation stage

Resource Block from example

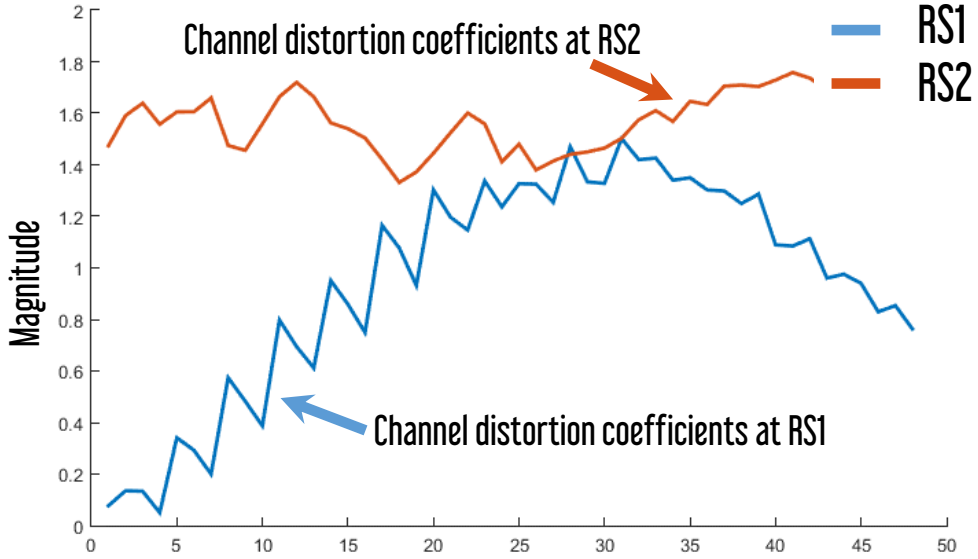
RS	Symbol 1	Symbol 2	Symbol 3
RS1	a_1	a_5	a_9
RS2	a_2	a_6	a_{10}
RS3	a_3	a_7	a_{11}
RS3	a_4	a_8	a_{12}

Typical Resource Block in LTE

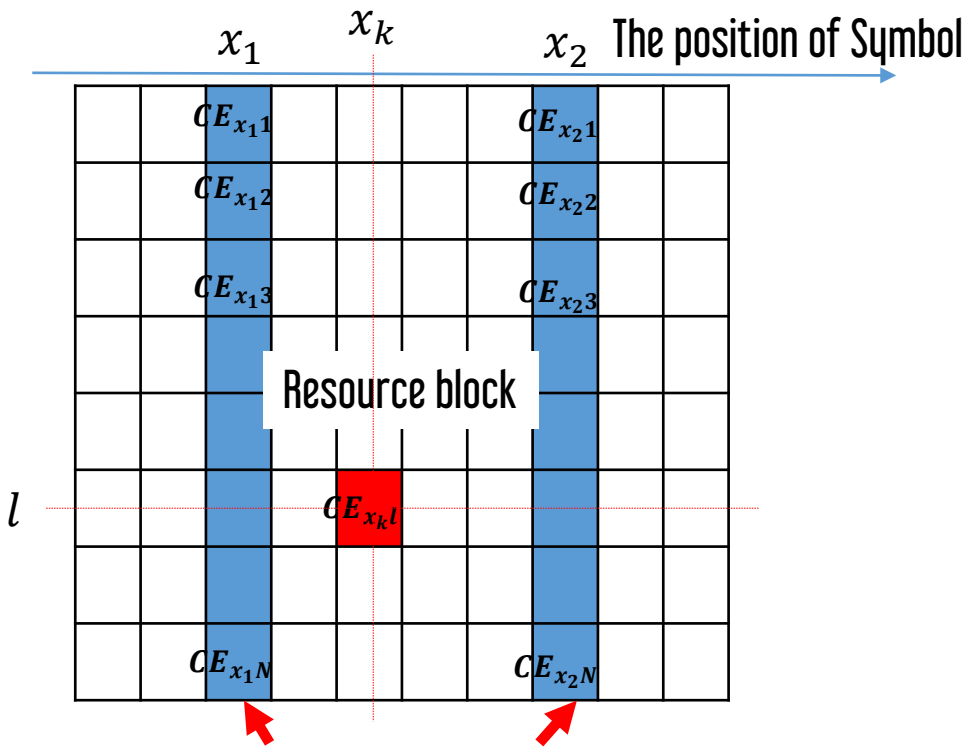


Data Symbols and Reference Symbols (blue blocks)

Channel estimation is performed by using RSs



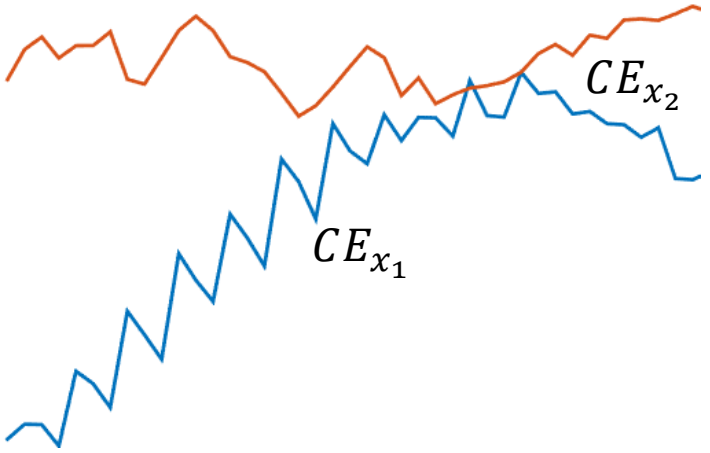
The main weak place in CE is approximation



We estimated the channel at these places

Linear approximation

$$CE_{x_k l} = \frac{CE_{x_2 l} - CE_{x_1 l}}{x_2 - x_1} (x_k - x_1) + CE_{x_1 l}$$



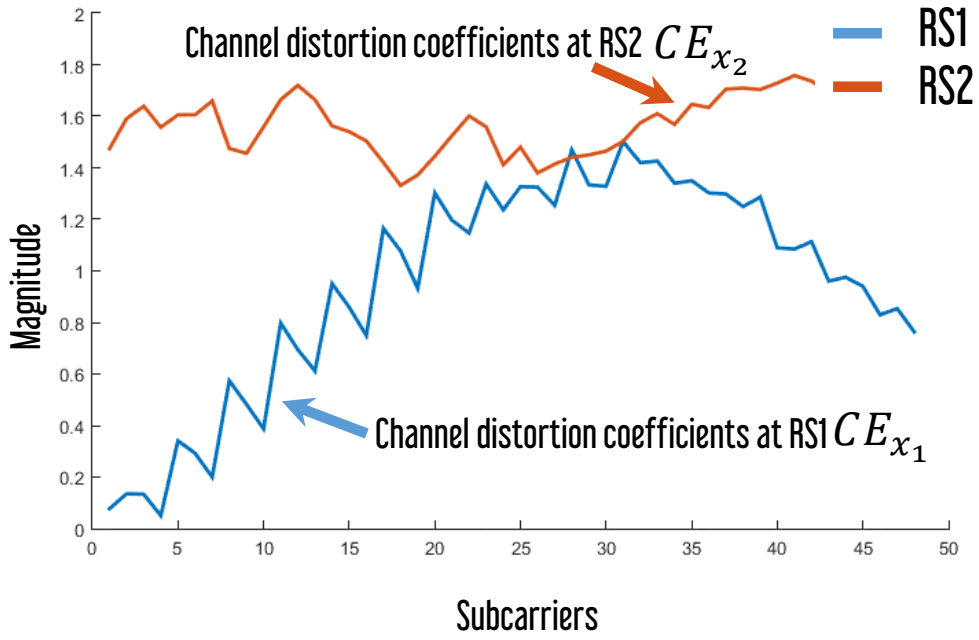
There are a lot of approaches in channel approximation,
we will consider the easiest one: linear approximation

Linear approximation results

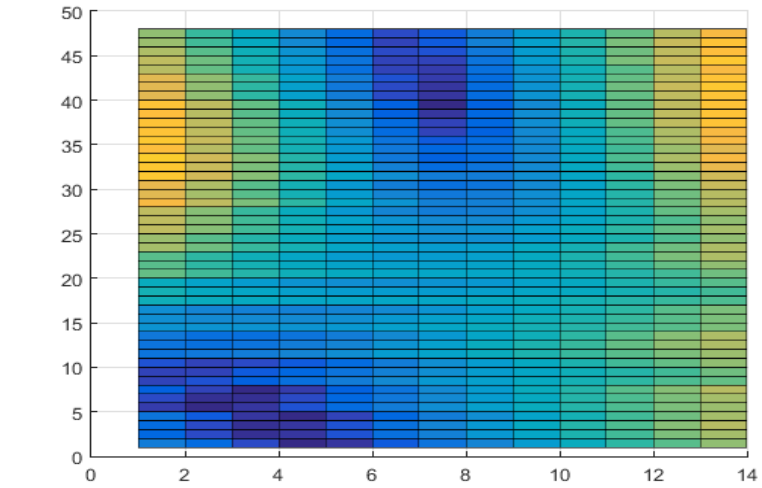
Linear approximation

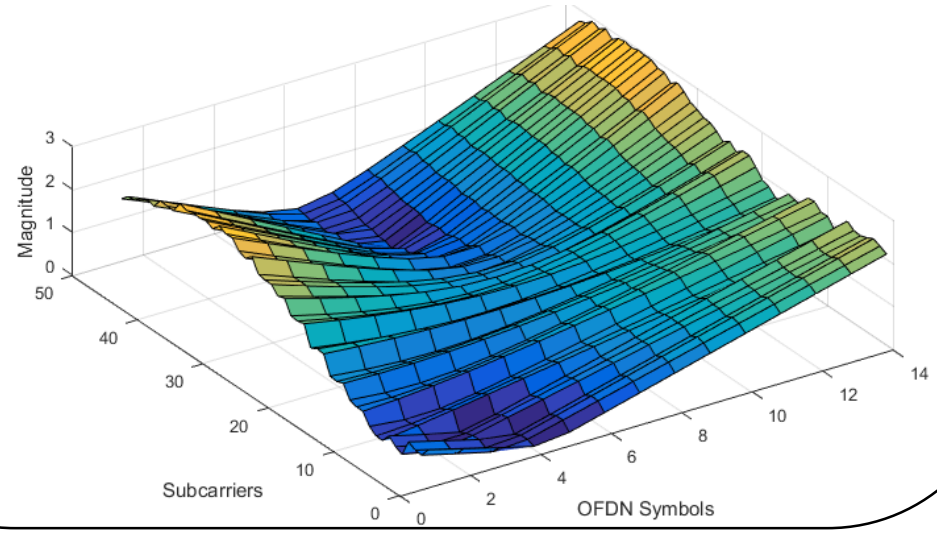
$$CE_{x_k l} = \frac{CE_{x_2 l} - CE_{x_1 l}}{x_2 - x_1}\,(x_k - x_1) + CE_{x_1 l}$$

Channel estimation is performed by using RSs

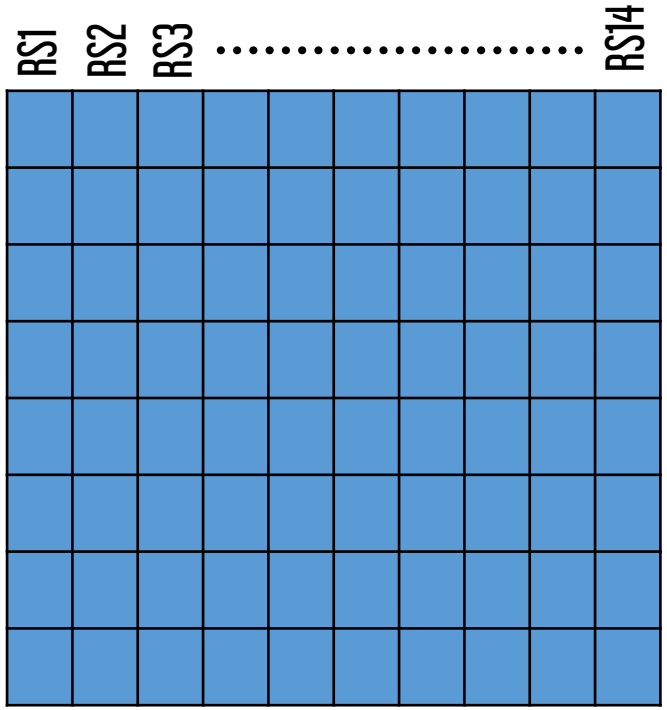


Linear Approximation



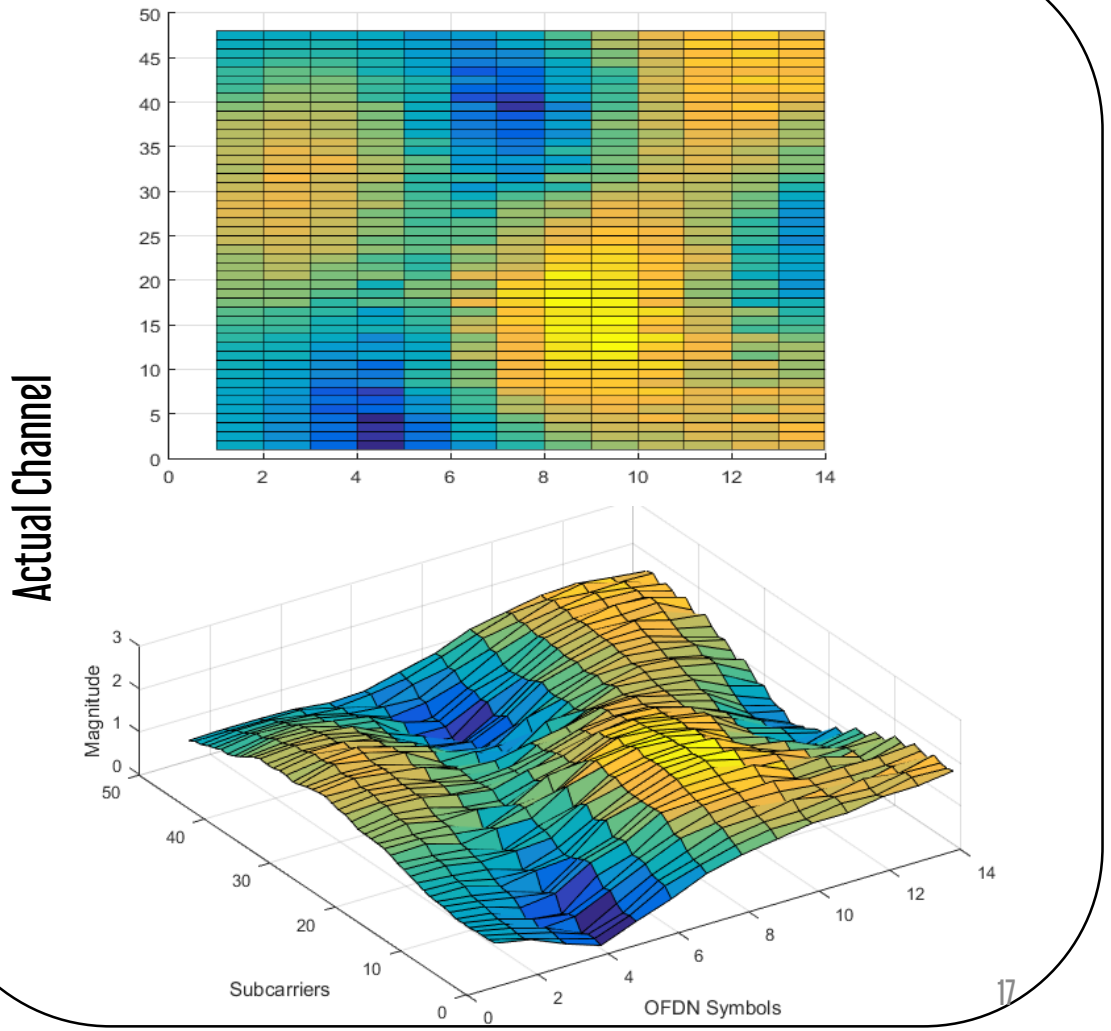


Calculation of actual channel



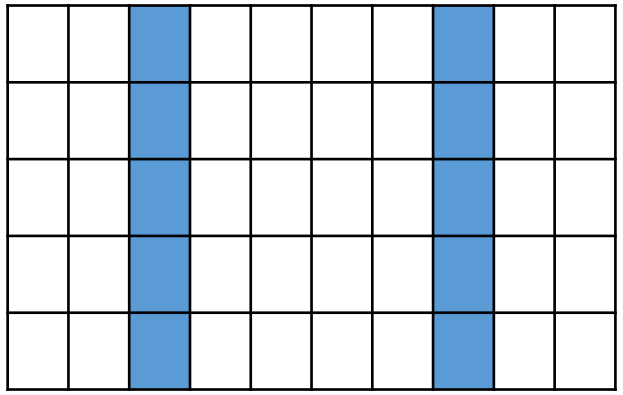
$$CE_{kl} = \frac{RS'_{kl}}{RS_{kl}}$$

Whole resource block is fill by reference symbols



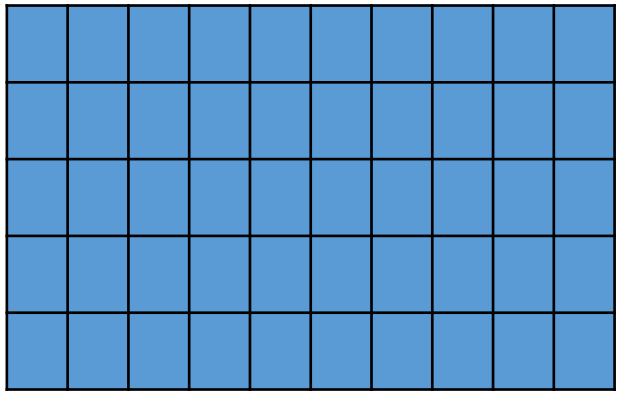
Comparison of Estimated Channel and Actual Channel

Two RSs among Symbols

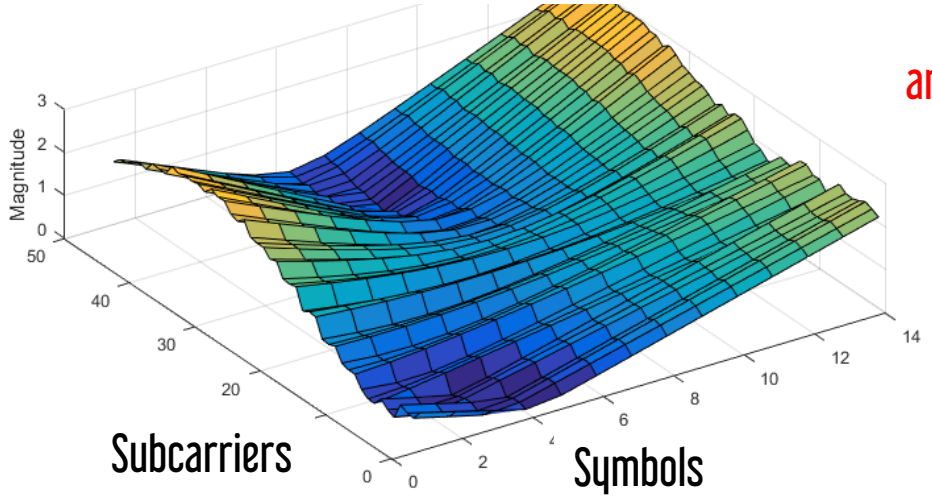


Multipath Channel is complicated object in wireless communication area, which must be accurately estimated for further correct data receiving (ref. page 10)

All Symbols are RS

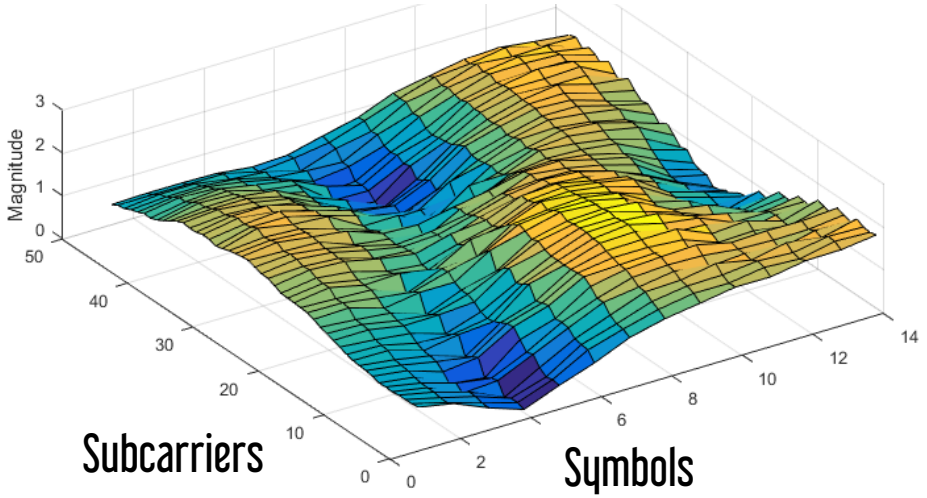


Not accurate estimation due to rough approximation

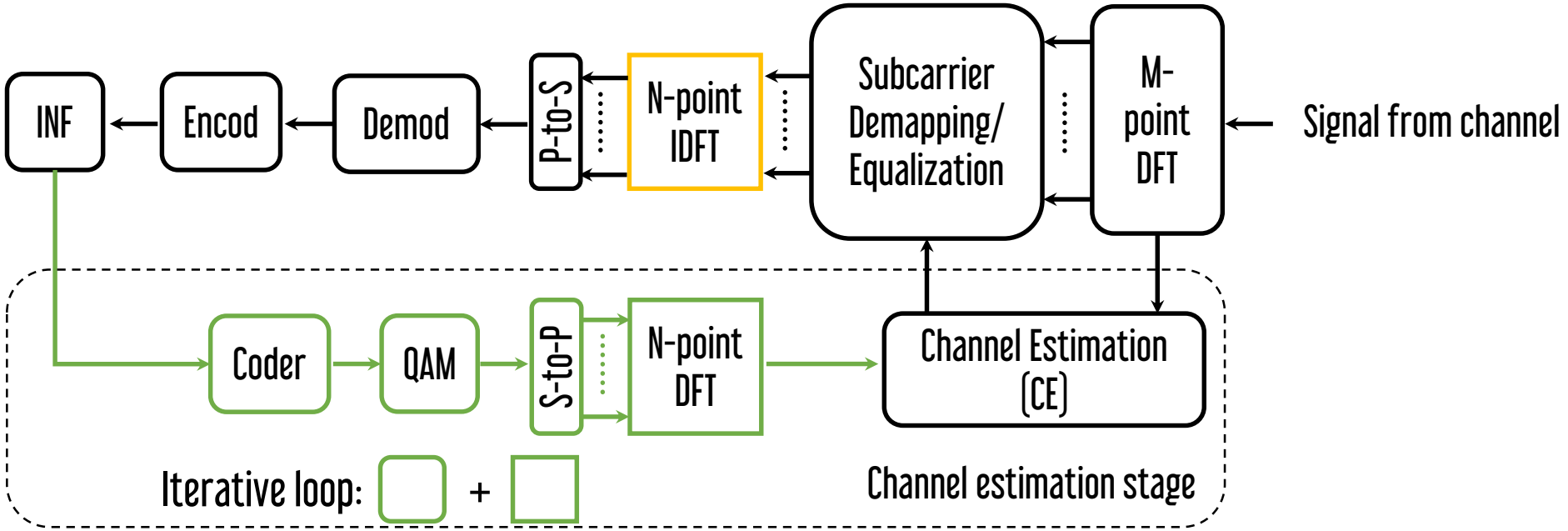


There is trade off between accuracy of CE and the amount of transmitted data

Accurate estimation because of all symbols were used as RS



Iterative algorithms of Channel estimation



Iterative procedure allows to use correctly received data as reference symbols and perform another attempt of channel estimation in order to obtain better accuracy. However, the complexity of this approach is very high, it is extremely time consuming procedure. How to optimally estimate multipath channel is still challenging in wireless communication

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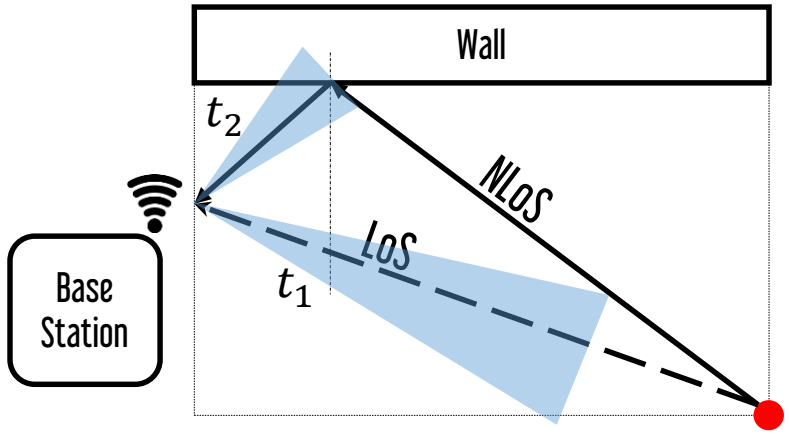
What is Multipath Channel

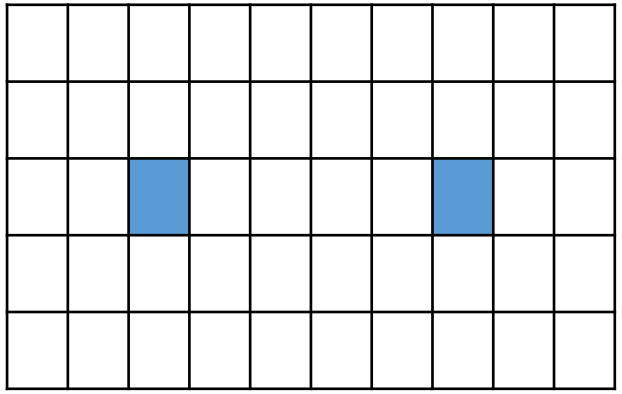


Due to multipath propagation, there are a number of path, through which signals come.

What if we somehow separate path and use them separately? Can it help us?

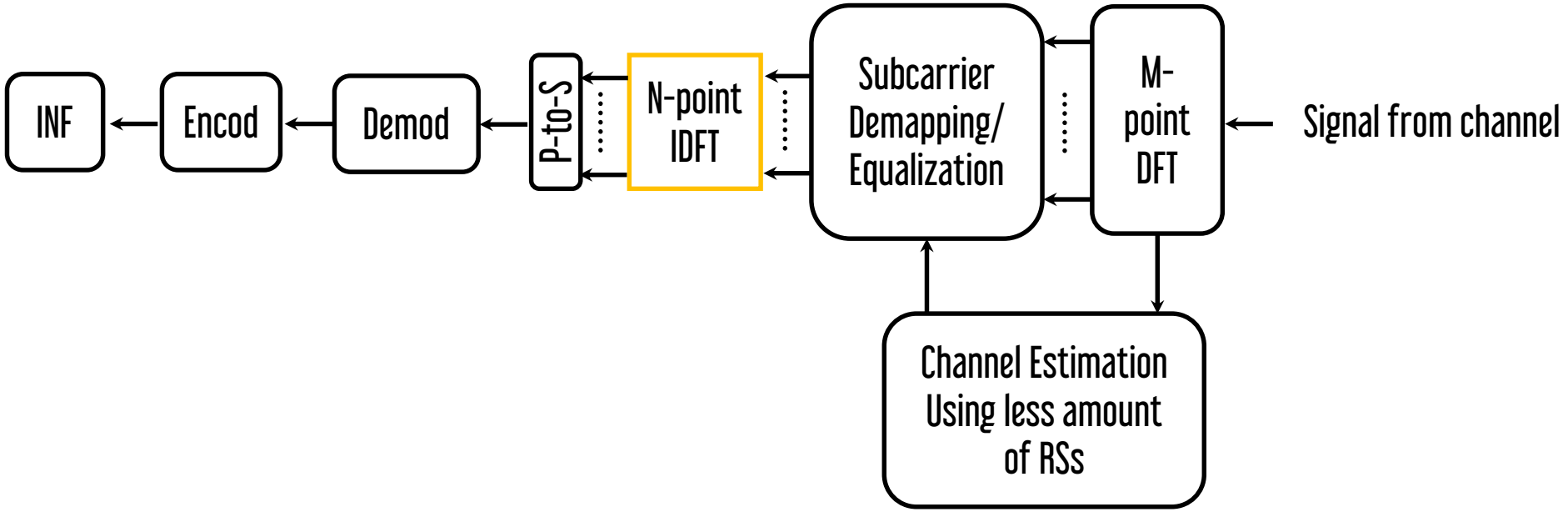
Base station in LTE network has MIMO antenna. It has ability to receive signals from a narrow sector. Thus, it can somehow scan area of receiving and find different path

1. Once we separate paths, we do not have deep fading effects anymore.
2. We do not have the following situation $s'(t) = s(t) + s(t + \tau)$.
3. Channel in one path is not frequency-selective. It has almost constant channel distortion coefficient through all orthogonal subcarriers
4. Typical resource block can be described as follows:



5. It allows to load more Data information instead RSs

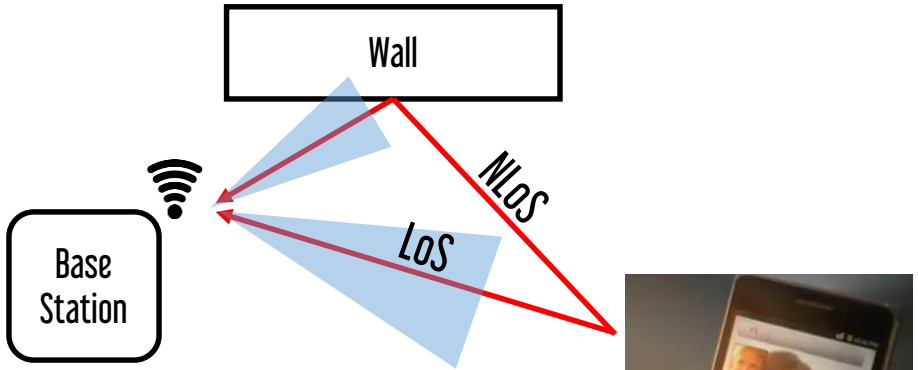
Simplified algorithm of Channel estimation



The algorithm of path separation can be computed in separated CPU. The main idea here is that the procedure of channel estimation will not delay Data receiving procedure.

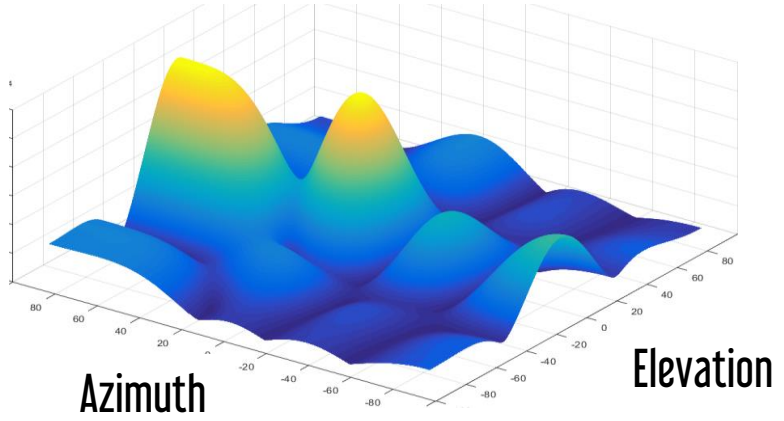
Can we separate paths? Yes

Simulation set up



There are one reflected NLoS and one LoS signals.

Two directions can be easily localized if there enough far



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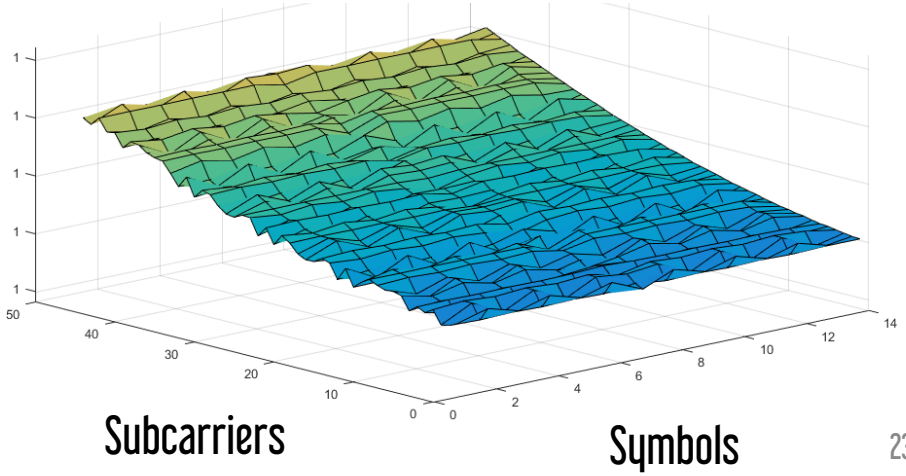

Next steps

- Create a platform for simulating the comprehensive environment for signal propagation
- Test different advanced algorithms of path separation, and evaluate their performance through extensive simulations
- Successful methods will be evaluated on real hardware. For this purpose, we are going to set up a testbed
- The project is partly supported by InternetNZ

Conclusions

- The existing algorithms of channel estimation have a lot of drawbacks such as: big complexity, time consuming, low accuracy. In addition, multipath propagation has big impact on channel estimation procedure

- Our solution can significantly decrease complexity of channel estimation or, even more, it can eliminate channel estimation nessessity

Thank you

Questions