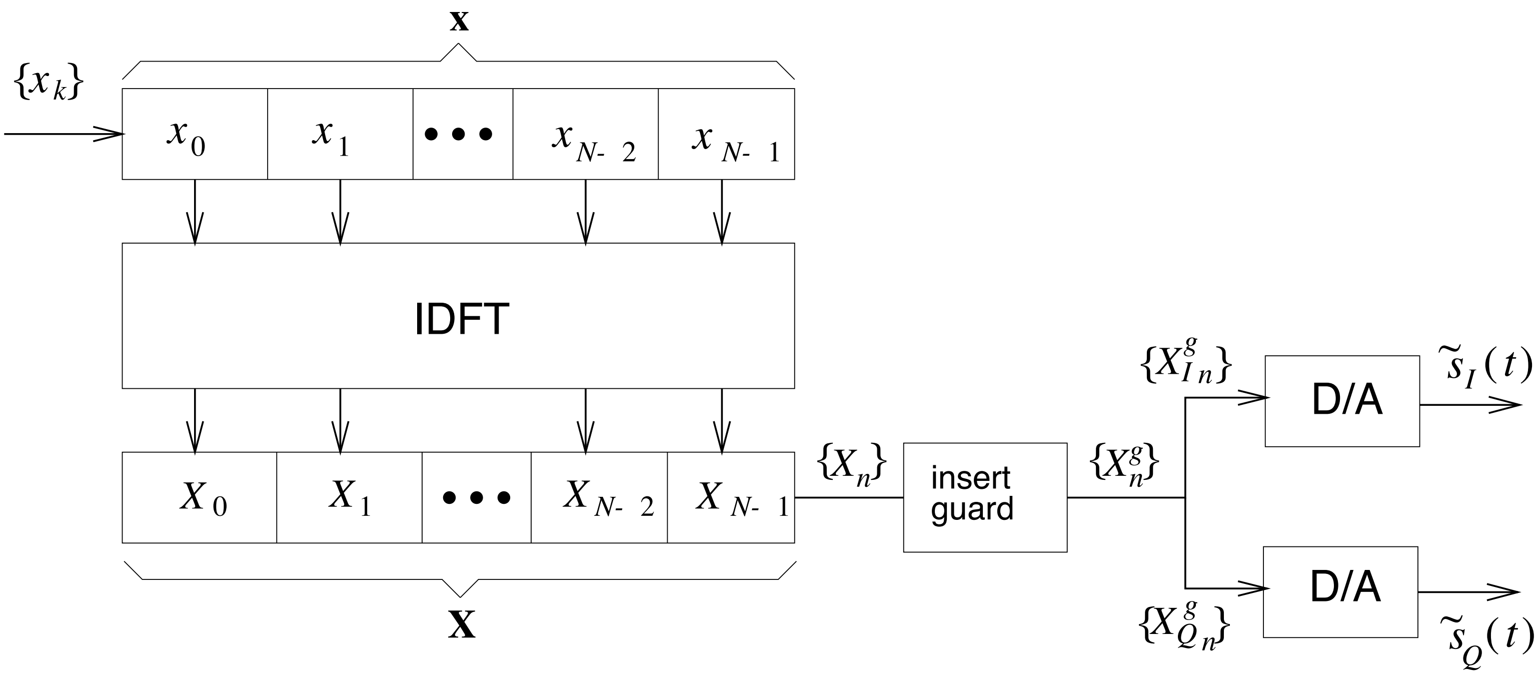
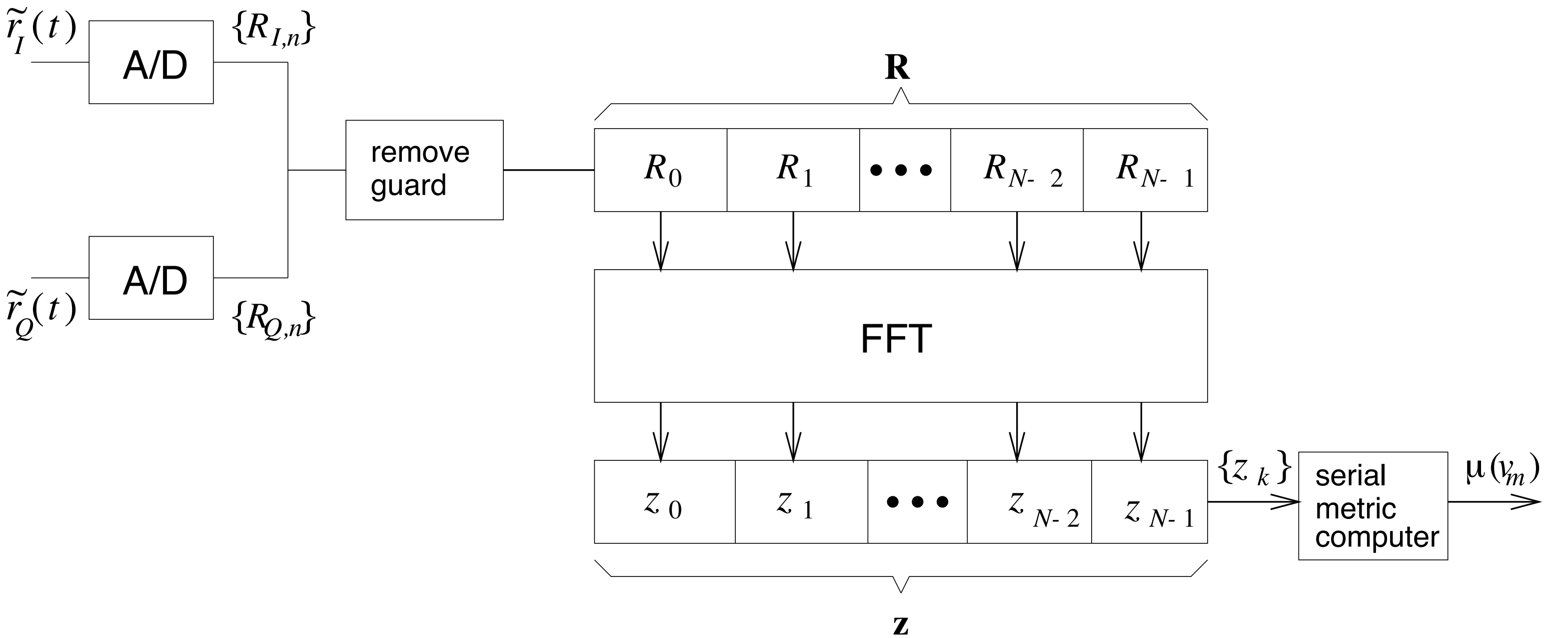
Multiple-Access Techniques
OFDMA and SC-FDMA



FFT-based OFDM Transmitter



FFT-based OFDM Receiver

OFDMA

- **OFDMA achieves multiple access by assigning different users disjoint sets of sub-carriers.**

- **Assume that there are a total of M sub-carriers that are evenly distributed among Q users, such that each user is allocated $N = M/Q$ sub-carriers. The overall sub-carriers are labeled with indices from 0 to $M-1$, while the N sub-carriers allocated to the jth MS have indices that belong to the set $\mathcal{T}_j$. Clearly, the sets $\mathcal{T}_j$ must be disjoint such that each sub-carrier is assigned to at most one MS.**

- **The sub-carrier allocation can be performed by extending the nth data vector for the jth MS, denoted, by $\mathbf{a}_{j,n}$ with the insertion of $M-N$ zeros in the sub-carriers belonging the set $\bar{\mathcal{T}}_j$ which is the complement of $\mathcal{T}_j$, i.e.,**

$$x_{j,n,i} = \begin{cases} a_{j,n,i} \ , & \textbf{if } i \in \mathcal{T}_j \\ 0 \ , & \textbf{otherwise} \end{cases} ,$$

where $a_{j,n,i}$ is the data symbol transmitted to the jth MS in block n on the ith sub-carrier.

OFDMA - Forward Link Transmitter

- **On the forward link, the vectors $\mathbf{x}_{j,n} = \{x_{j,n,i}\}_{i=0}^{M-1}$ are summed up to produce the nth data block**

$$\mathbf{x}_n = \sum_{j=1}^{Q} \mathbf{x}_{j,n}$$

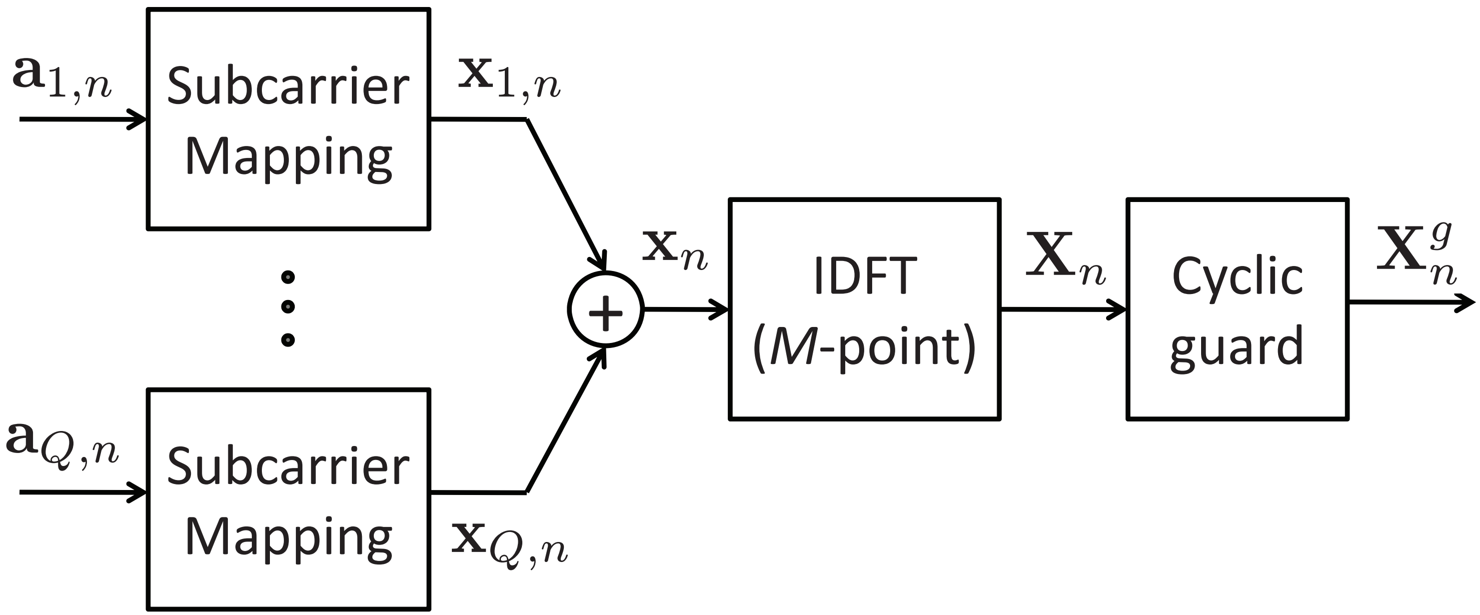
that is subsequently applied to an M-point IDFT to produce the length-M time-domain sequence $\mathbf{X}_n$.

- **After the IDFT, a length-G guard interval is appended to each block in the form of a cyclic prefix or cyclic suffix, to yield the transmitted time-domain sequence $\mathbf{X}_n^g$.**

- **In the case of a cyclic prefix, the last G symbols of the sequence $\mathbf{X}_n = \{X_{n,m}, \quad m = 0, \ldots, M-1\}$ are copied and appended to the beginning of $\mathbf{X}_n$. The transmitted time-domain sequence for the nth block with guard interval, denoted as $\mathbf{X}_n^g$, is**

$$\mathbf{X}_n^g = \{X_{n,(m)_M}, \quad m = -G, -G+1, \cdots, -1, 0, 1, \cdots, M-1\} \ ,$$

where $(m)_M$ is the residue of m modulo-M.



Baseband OFDMA forward link BS transmitter.

OFDMA - Sub-carrier Allocation

- **Clustered Carrier (CC-OFDMA): With CC-OFDMA, the M sub-carriers are divided into Q groups where each group consists of N contiguous sub-carriers called clusters. The set of sub-carrier indices allocated to the kth user is $\{kN, kN+1, \ldots, kN+N-1\}$, where $0 \leq k < Q$. CC-OFDMA is sensitive to frequency-selective fading, because all sub-carriers assigned to a particular user may fade simultaneously.**

- **Spaced Carrier (SC-OFDMA): With SC-OFDMA, the M sub-carriers are partitioned into N groups, where each group has Q contiguous sub-carriers. Then the kth sub-carrier of each group is assigned to the kth user. That is, the kth user is assigned the set of sub-carrier indices $\{k, Q+k, \ldots, (N-1)Q+k\}$, where $0 \leq k < Q$. SC-OFDMA is less sensitive to frequency-selective fading, since the sub-carriers assigned to each user span the entire bandwidth.**

- **Random Interleaving (RI-OFDMA): RI-OFDMA is used in IEEE802.16a. While the sub-carriers are partitioned into N groups as in SC-OFDMA, the sub-carrier index in each of the N groups that is assigned to a particular user is a random variable. The sub-carrier indices allocated to the kth user are $\{\epsilon_{k,1}, Q+\epsilon_{k,2}, \ldots, (M-1)Q+\epsilon_{k,M-1}\}$, where the $\epsilon_{k,i}$ are independent and identically distributed uniform random variables on the set $\{0, 1, \ldots, Q-1\}$.**

OFDMA - Forward Link Receiver

- **To remove the ISI introduced by the channel, the guard interval is removed. If the length of the cyclic prefix is at least as long as the discrete-time channel length, i.e., $G \geq L$, then we obtain the received sequence**

$$\begin{aligned} R_{n,m} &= R^g_{n,m} \\ &= \sum_{i=0}^{L} g_i X_{n,(m-i)_M} + \tilde{n}_{n,m} \ , \quad 0 \leq m \leq M-1 \ , \end{aligned}$$

- **Afterwards, an M-point IDFT is taken to transform to the frequency domain. This yields the output vector**

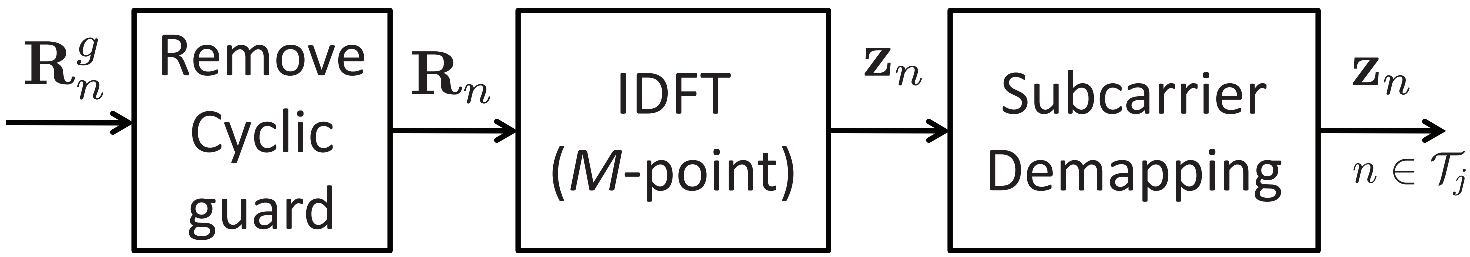
$$\begin{aligned} z_{n,i} &= \frac{1}{M} \sum_{m=0}^{M-1} R_{n,m} \mathrm{e}^{-j\frac{2\pi mi}{M}} \\ &= T_i A x_{n,i} + \nu_{n,i} \ , \quad 0 \leq i \leq M-1 \ , \end{aligned}$$

  where

$$T_i = \sum_{m=0}^{L} g_m \mathrm{e}^{-j\frac{2\pi mi}{M}}$$

  and the noise samples $\{\nu_{n,i}\}$ are i.i.d with zero-mean and variance $N_o/(MT^g_s)$.

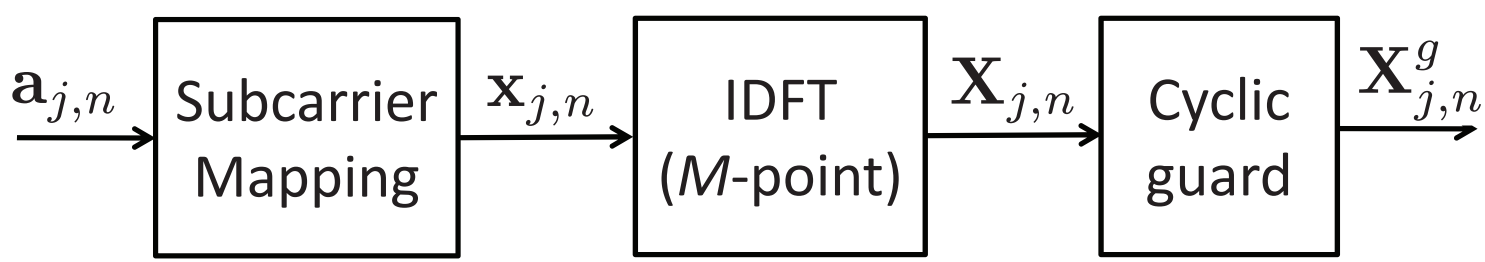
- **On the forward link each MS will only be interested in the N data symbols that are transmitted by the BS on its allocated sub-carriers. Hence, only the DFT outputs with indices in the set $\mathcal{T}_j$ are used by the jth MS for data detection.**



Baseband OFDMA forward link receiver.

OFDMA - Reverse Link

- On the OFDMA reverse link, Q users transmit their signals to a central BS.
- Each MS transmitter only transmits its own data stream.
- Similar to the OFDMA forward link, the jth MS performs sub-carrier allocation, and the resulting vector $\mathrm{x}_{j,n}$ is applied to an M-point IDFT, and appended with a length-G cyclic guard interval.
- One of the biggest drawbacks of OFDMA is its high PAPR. A high PAPR may be acceptable on the forward link; however, a high PAPR is undesirable on the reverse link since the MS is often is often battery powered and amplifier back-off is required.



Baseband OFDMA reverse link MS transmitter.