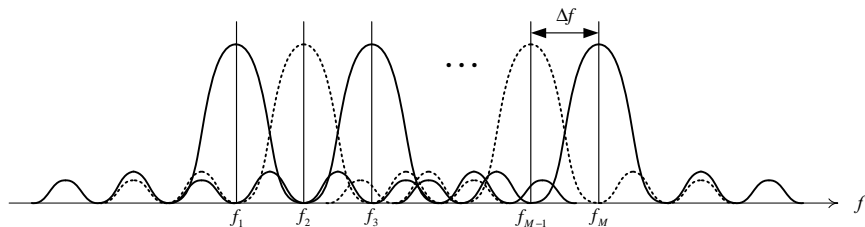
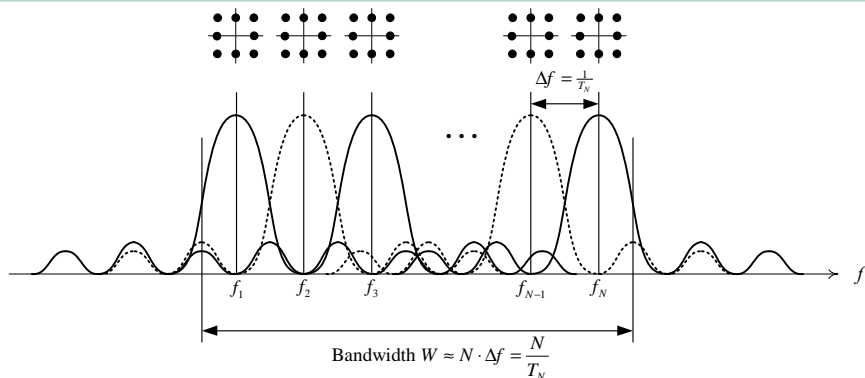


Spectrum of M -FSK



- In M -FSK, only one carrier is active in any given symbol duration to carry $\log_2 M$ bits. This is why it is not a spectral-efficient modulation scheme.
- Why not using all the carriers to carry information at the same time since they are orthogonal? This leads to OFDM (orthogonal frequency-division multiplexing) technique.

OFDM (Orthogonal Frequency-Division Multiplexing)



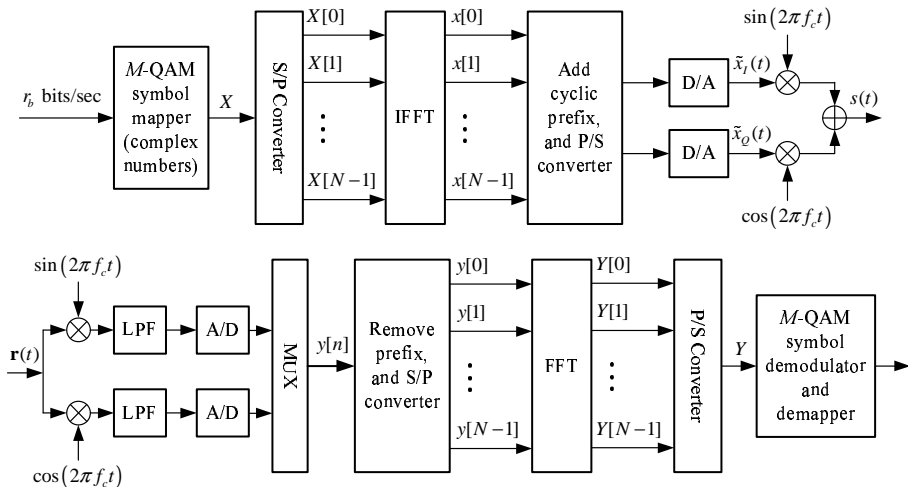
- In OFDM the spectrum (frequency) is divided into *overlapping* but *orthogonal* subcarriers. Each sub-carrier is independently modulated by M -QAM. The minimum subcarrier separation is $1/T_N$, where T_N is the OFDM symbol length.
- OFDM can be simply looked upon as a combination of *amplitude*, *phase* and *frequency* modulation techniques.

Communication Services using OFDM

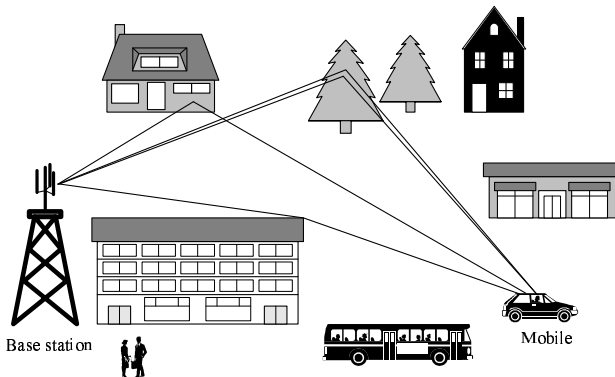
Wireless	Wireline
IEEE 802.11a, g, n (WiFi) Wireless LANs	ADSL and VDSL broadband access via POTS copper wiring
IEEE 802.15.3a Ultra Wideband (UWB) Wireless PAN	MoCA (Multi-media over Coax Alliance) home networking
IEEE 802.16d, e (WiMAX), WiBro, and HiperMAN Wireless MANs	PLC (Power Line Communication)
IEEE 802.20 Mobile Broadband Wireless Access (MBWA)	
DVB (Digital Video Broadcast) terrestrial TV systems: DVB -T, DVB -H, T-DMB, and ISDB-T	
DAB (Digital Audio Broadcast) systems: EUREKA 147, Digital Radio Mondiale, HD Radio, T-DMB, and ISDB-TSB	
Flash-OFDM cellular systems	
3GPP UMTS & 3GPP@ LTE (Long-Term Evolution), and 4G	

OFDM is spectrally efficient, tolerates environments with high RF interference, works well in harsh multi-path environments and can be elegantly implemented with IFFT/FFT modules.

Implementation of OFDM



Multipath Problem in High-Speed Wireless Transmission

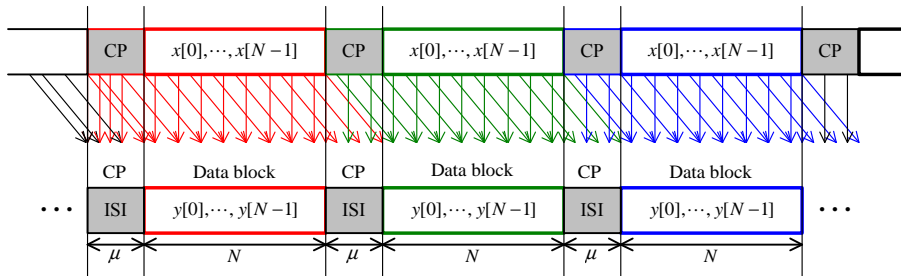
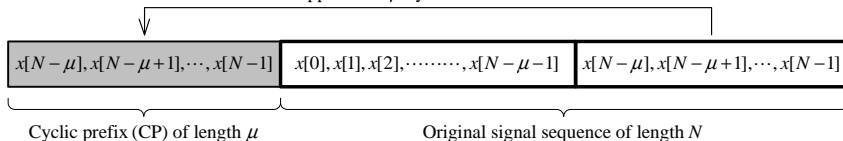


(b) Mobile wireless channel

Example: Consider the symbol rate of 10^6 symbols/sec \Rightarrow The receiver expects a specific symbol within a window of $1 \mu\text{s}$. If multi-path delays the signal by more than $1 \mu\text{s}$ (easily happen in real propagation environment), then the receiver will also receive the symbol in the next symbol period, causing *inter-symbol-interference* (ISI), hence severe performance degradation.

How Does Cyclic Prefix Work in OFDM

Append last μ symbols to the front



- An OFDM symbol is basically a *super-symbol* obtained by multiplexing many M -QAM symbols in a complicated manner. The length of a super-symbol (T_N) becomes longer and hence more resistant to multipath effect.
- One can also use *zero padding* to create a *guard interval* between consecutive OFDM symbols, hence avoiding ISI.