2.1.3 Multipath Fading:

The signal in UWA propagates to the destination over multiple paths because of signal reflections from the surface and bottom, and signal refractions due to spatial variability of the water. The sound speed depends on the salinity, temperature, and pressure of the water, which differ in space. This implies that a signal traveling over longer path does not necessarily means that it will arrive at the destination after a signal traveling over shorter path, because the former may travel in higher speed than the latter. However, sound speed can be taken as constant over shallow water channels [4]. Furthermore, these propagation paths are time varying, i.e.: at specific time t the CIR is given by [6]:

$$c(t;\tau) = \sum_{p} A_p(t)\delta\Big(t - \tau_p(t)\Big) \tag{2.8}$$

where $A_p(t)$ and $\tau_p(t)$ are the time-varying channel gain and delay associated with p^{th} path, respectively. Contrary to the RF channels, in UWA channels, there is no consensus regarding the distribution of the channel taps, where in some channels they are well modeled as deterministic, while in others they can be modeled as Rician or Rayleigh [5]. Most authors consider shallow-water medium range channels as Rayleigh. Also deep water channels modeled as Rayleigh. However, the available measurements are scarce, making channel modeling controversial [1].

Because of low propagation speed of sound, multipath delay spread is usually very long, which causes severe Intersymbol Interference (ISI), e.g.: it is not unusual to have a delay spread of 100 ms, which results in ISI of length 500 symbols for transmission rate of 5 Kilo symbol per second (Ksps) [7]. Also, there are just a small number of significant paths in the CIR, which makes UWA channels sparse in nature [8]. On the other hand, the time-variability of UWA is due to two reasons: inherent changing in the medium, and the relative motion between the transmitter and receiver [4]. In shallow water, the main contributor of time-variability is the surface waves, which cause the displacement of the reflection points. On the other hand, in deep water internal waves contribute to the time-variability of the medium. Motion of the reflection points causes frequency spreading of the surface-reflected signal. The frequency spreading of a signal component of frequency f and with incidence angle of θ is $0.0175(f/c)w^{3/2}\cos(\theta)$, where c is the sound speed. For general design purpose, a coherence time in the order of 100 ms may be assumed [5].

2.1.4 Doppler Effect:

Also, a moving transmitter and/or receiver, either voluntarily or involuntarily, cause time-variability, which causes Doppler shift proportional to the factor $a = v/c$, where v is the relative speed between the transmitter and receiver [1]. Because of the low speed of sound in UWA channels, this factor is significant and can not be ignored as it is the case in most RF channels.

In narrow-band systems, where the signal bandwidth is much smaller than the carrier frequency, which is the case in RF channels, the effect of Doppler on a communication system is

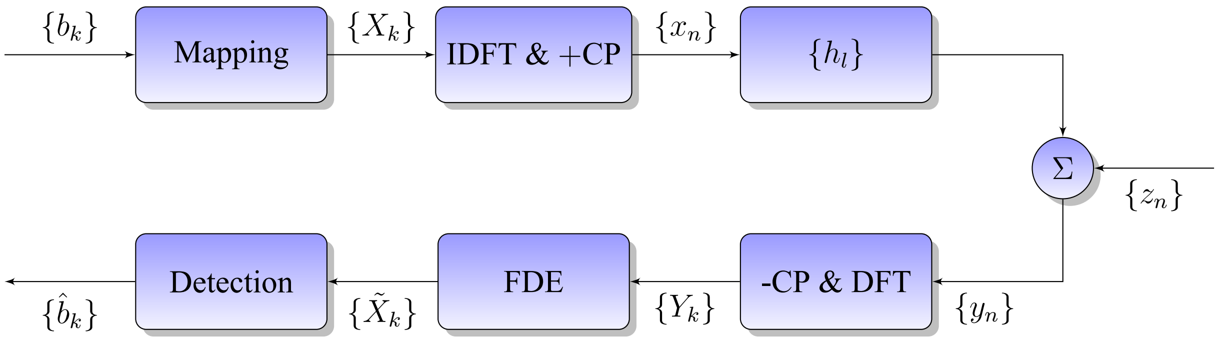

Figure 2.5: OFDM block diagram

approximated as carrier frequency shift, which can be compensated for by adjusting the local carrier frequency [9]. However, in wide-band signals as in UWA, where the the signal bandwidth is comparable to the carrier frequency, each frequency component is affected differently. In this case it is more accurate to model the Doppler effect as time scaling, i.e., $r(t) = s\big((1+a)t\big)$, where $r(t)$ is the received signal, a and $s(t)$ is the transmitted signal, and hence time synchronization is needed in this case as well as frequency synchronization. Sampling $r(t)$ gives at the sampling time T_s:

$$r[nT_s] = s\Big[n(1+a)T_s\Big] \tag{2.9}$$

So, to get rid of the Doppler effect, the sampling time must be adjusted at $T_s/(1+a)$ [9], which yields:

$$r\Bigg[\left(\frac{n}{1+a}\right)T_s\Bigg] = s[nT_s] \tag{2.10}$$

A major design parameter here is the accuracy of the factor a, and the residual Doppler the tolerated by an adaptive equalizer, where a residual Doppler of the order 10^{-4} is needed to a Decision Feedback Equalizer (DFE) equalizer to track the changes, otherwise, it diverge [9]. In [6] it was shown that the preprocessing resampling converts the wide-band signal to a narrow-band signal, where Carrier Frequency Offset (CFO) can be used to eliminate the residual Doppler effect resulting from the estimation error of the factor a.

2.2 OFDM and SC-FDE:

In this section, we are going to present the basics of both OFDM and SC-FDE in both quasi-static and time-varying frequency selective channels, and make a comparison between the two schemes.