RAKE Receiver

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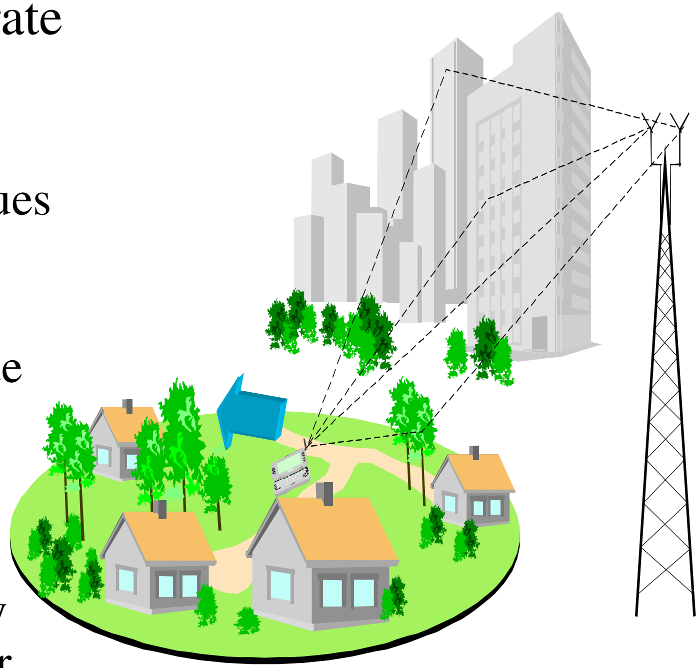
Agenda

- Introduction
- Multipath Channel
- M-finger RAKE Receiver
- RAKE Receiver Blocks
- RAKE Receiver Requirements
- RAKE Receiver in IS-95 System
- RAKE Receiver in WCDMA System
- Conclusions
- References
- Homework

Introduction (1)

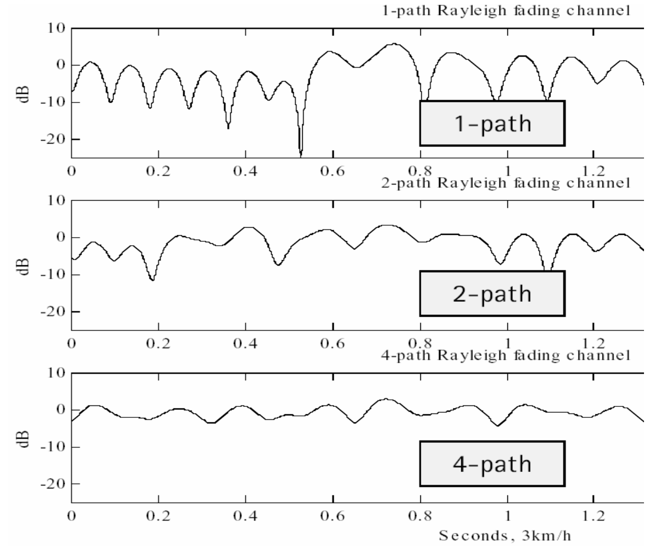
- In CDMA spread spectrum systems, the chip rate is typically much greater than the flat fading bandwidth of the channel
  - Conventional modulation and receiver techniques require an equalizer to undo the ISI between adjacent symbols
  - CDMA spreading codes are designed to provide very low correlation between successive chips
- Propagation delay spread in the radio channel provides multipath signal at the receiver
  - If multipath components are delayed in time by more than one chip duration ($1/R_c$), they appear like uncorrelated noise at a CDMA receiver, and equalization is not required

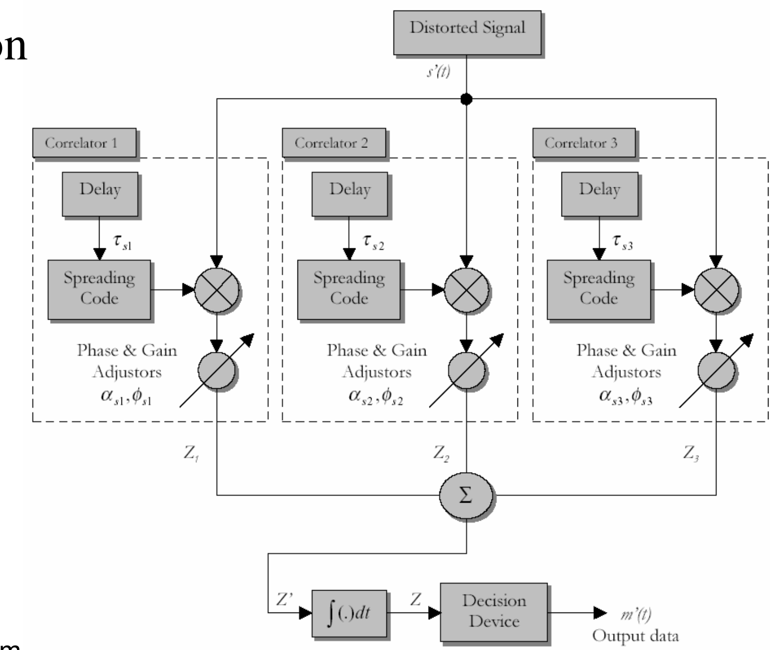
-> RAKE type correlator receiver can be used!!!



Introduction (2)

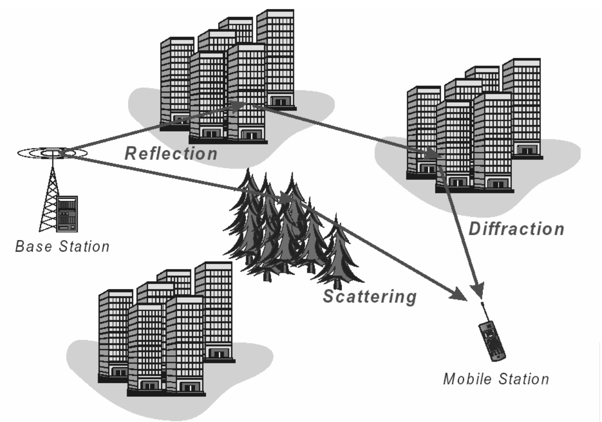
- RAKE receiver, used specially in CDMA cellular systems, can combine multipath components
  - To improve the signal to noise ratio (SNR) at the receiver
  - Provides a separate correlation receiver for each of the multipath signals
  - Multipath components are practically uncorrelated when their relative propagation delay exceeds one chip period
- The basic idea of A RAKE receiver was first proposed by Price and Green and patented in 1956

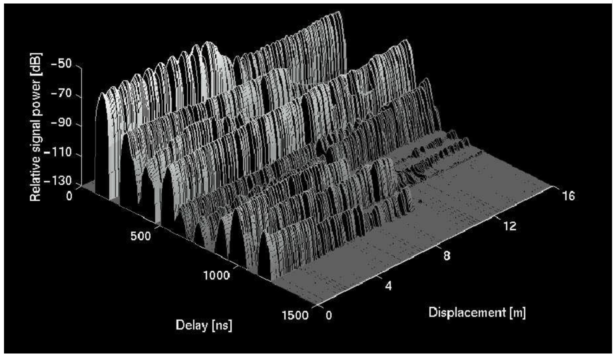


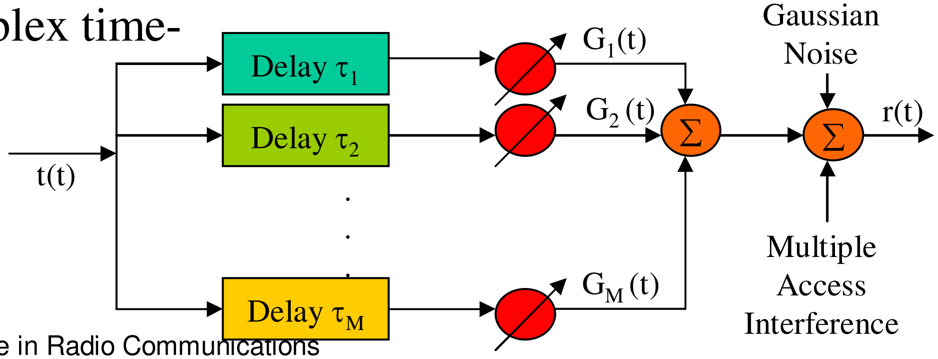


Multipath Channel

- Due to reflections from obstacles a radio channel can consist of many copies of originally transmitted signals having
  - different amplitudes, phases, and delays
- Multipath can occur in radio channel in various ways
  - Reflection, diffraction, scattering
- The RAKE receiver uses a multipath diversity principle
  - It rakes the energy from the multipath propagated signal components
- M-ray multipath model can be used
  - Each of the M paths has an independent delay, t, and an independent complex time-variant gain, G
  - t(t) is transmitted signal
  - r(t) is received signal

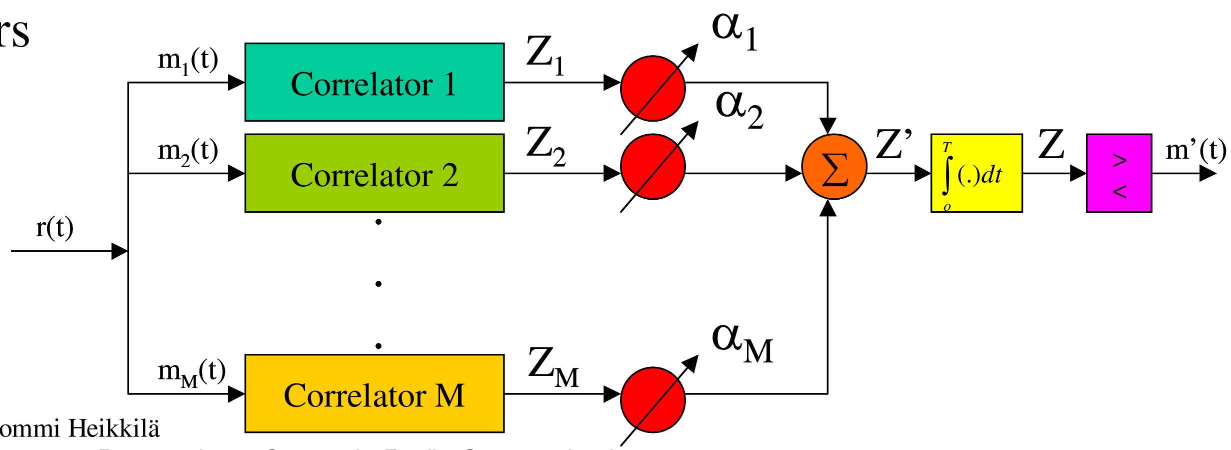






M-finger RAKE Receiver (1)

- RAKE receiver utilizes multiple correlators to separately detect M strongest multipath components
- Each correlator detects a time-shifted version of the original transmission, and each finger correlates to a portion of the signal, which is delayed by at least one chip in time from the other fingers
- The outputs of each correlator are weighted to provide better estimate of the transmitted signal than is provided by a single component
  - Outputs of the M correlators are denoted as Z_1, Z_2,…, and Z_M
  - Outputs are weighted by α_1, α_2,…, and α_M, respectively
- Demodulation and bit decisions are then based on the weighted outputs of the M correlators



M-finger RAKE Receiver (2)

- The weighting coefficients are based on the power or the SNR (Signal-to-Noise Ratio) from each correlator output
  - If the power or SNR is small out of a particular correlator, it will be assigned a small weighting factor, α.
  - If maximal-ratio combining is used, following can be written for Z'

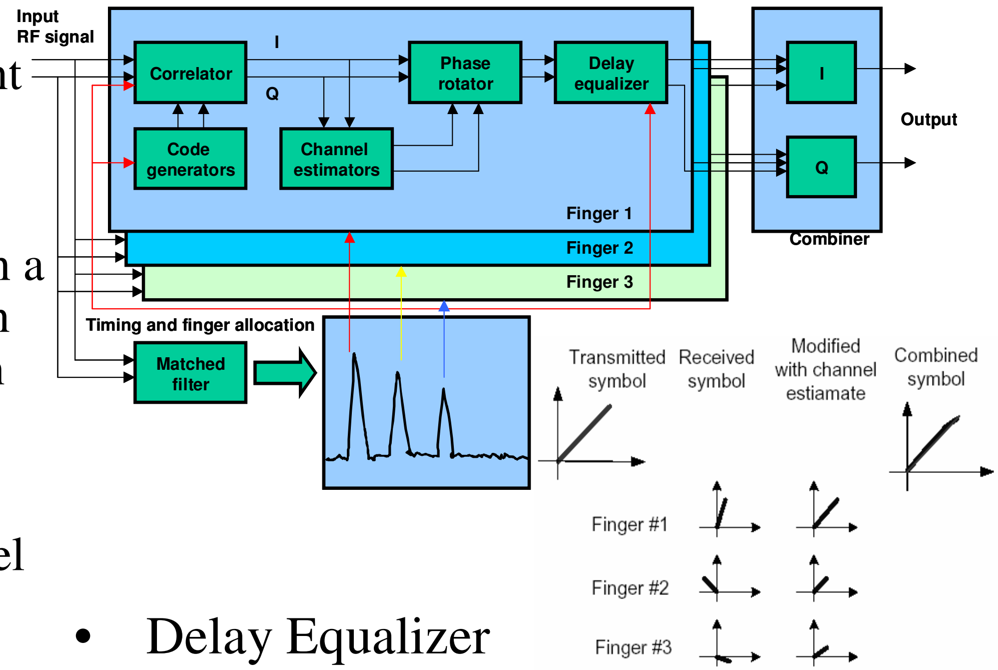
$$Z' = \sum_{m=1}^{M} \alpha_m Z_m$$

- The weighting coefficients, α_m, are normalized to the output signal power of the correlator

$$\alpha_m = \frac{Z_m^2}{\sum_{m=1}^{M} Z_m^2}$$

- There are many ways to generate the weighting coefficients
  - Due to Multiple Access Interference, RAKE fingers with strong multipath amplitudes will not necessarily provide strong output after correlation
  - Choosing weighting coefficients based on the actual outputs of the correlator yields to better RAKE performance

RAKE Receiver Blocks



- Matched filter
  - Impulse Response Measurement
  - Largest peaks to RAKE fingers
  - Timing to delay equalizer
  - Tracks and monitors peaks with a measurement rate depending on speeds of mobile station and on propagation environment
- Code Generators
  - PN codes for the user or channel
- Correlator
  - Despreading and integration of user data symbols
- Channel Estimator
  - Channel state estimate
  - Channel effect corrections
- Phase Rotator
  - Phase correction
- Delay Equalizer
  - Compensates delay for the difference in the arrival times of the symbols in each finger
- Combiner
  - Adding of the channel compensated symbol
  - Multipath diversity against fading

RAKE Receiver Requirements (1)

- RAKE receiver has to know
  - Multipath delays -> time delay synchronization
  - Phases of the multipath components -> carrier phase synchronization
  - Amplitudes of the multipath components -> amplitude tracking
  - Number of multipath components -> RAKE allocation
- Time delay synchronization is based on correlation measurements
  - Delay acquisition
  - Delay tracking by feedback loops (delay-locked loops, DLL)
- Due to fading channels conventional phase-locked loop (PLL) cannot be used in carrier and amplitude tracking
- Number of available fingers depends on the channel profile and the chip rate
  - The higher the chip rate, the more resolvable paths there are
  - A very large number of fingers lead to combining losses and practical implementation problems
- The main challenges for RAKE receivers operating in fading channels are in receiver synchronization

RAKE Receiver Requirements (2)

- High bandwidth (5 MHz in WCDMA) and dynamic interference inherent to WCDMA requires that RF and IF parts have to operate linearly with large dynamic range.
- In practical RAKE receivers synchronization sets some requirements
  - Automatic Gain Control (AGC) loop is needed to keep the receiver at the dynamic range of the A/D converter (Analog-to-Digital).
  - AGC must be fast and accurate enough to keep receiver at the linear range
  - Frame-by-frame data range change may set higher AGC and A/D converter requirements
  - The high sampling rates of few tens of MHz and high dynamics of the input signal (80 dB) require fast A/D converters and high resolution

RAKE Receiver in IS-95 System (1)

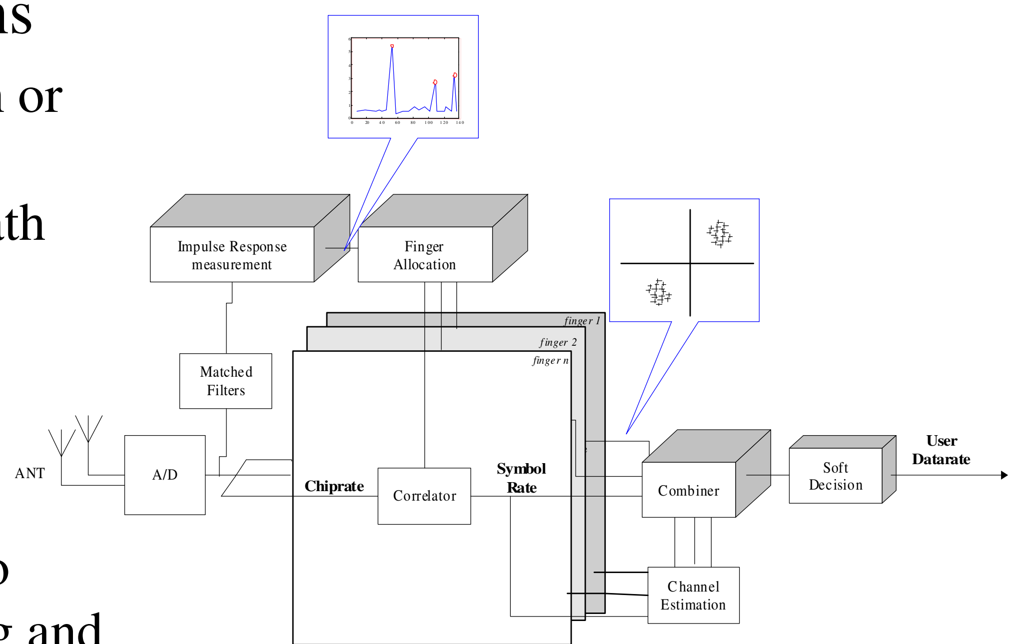
- In the implementation of the IS-95 system, the mobile receiver employs
  - A "searcher" receiver (matched filter)
  - Three digital data receivers that act as fingers of a RAKE
  - The PN chip rate of 1,2288 MHz allows for resolution of multipaths at time intervals of 1,2288 x 10^{-6} s = 0,814 ms
- Downlink
  - The searcher receiver scans the time domain about the desired signal's expected time of arrival for multipath cell's pilot signals
  - Pilot channel permits the coherent detection of signals via phase offsets
  - The search receiver indicates to the mobile phone's control processor where, in time, the strongest replicas of the signal can be found, and their respective signal strengths
  - The control processor provides timing and PN code information to the tree digital data receivers, enabling each of them to track and demodulate a different signal
  - The data from all three digital receivers are combined for improved resistance to fading

RAKE Receiver in IS-95 System (2)

- Uplink
  - If the base station receiver uses two antennas for space diversity reception, and there are four digital data receivers available for tracking up to four multipath components of a particular subscriber's signal
  - The searcher receiver at the base station can distinguish the desired mobile signal by means of its unique scrambling long PN code offset
  - Code offset is acquired before voice or data transmission begins
  - No coherent phase reference like the downlink's pilot signal
  - Must be demodulated and combined non-coherently

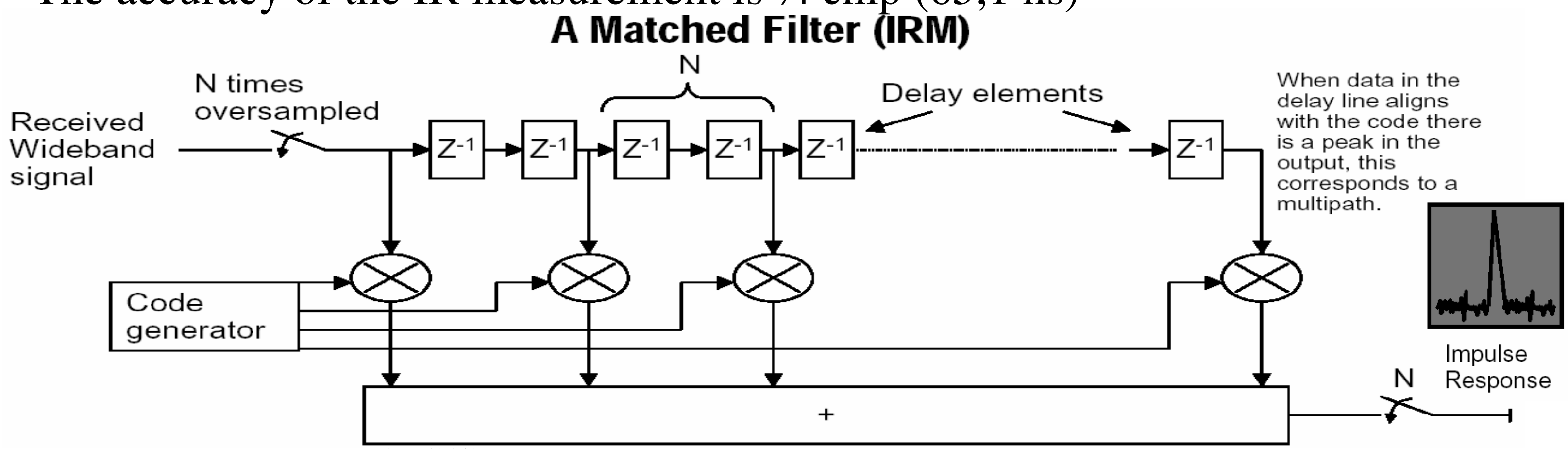
RAKE Receiver in WCDMA System (1)

- RAKE receiver functions
  1. Channel delay estimation or Impulse Response (IR) Measurement for multipath components
  2. RAKE receiver finger allocation based on the channel delay estimation
  3. RAKE receiver fingers to perform the descrambling and despreading operations
  4. Adaptive Channel Estimation
  5. Maximal-Ratio Combining



RAKE Receiver in WCDMA System (2)

- Channel Delay Estimation
  - Yields both timing and phase information of the channel
  - Impulse Response Measurement (IRM) is performed by using Matched Filter (MF) type of correlators
  - Length of the matched filter determines the total delay spread that can be resolved (length of 64 chips time period for RACH and 32 chips time period for DPCCH)
  - Add averaging and thresholding, and the channel estimator is complete
  - Requires a lot of processing -> power consumption
  - The accuracy of the IR measurement is ¼ chip (65,1 ns)



RAKE Receiver in WCDMA System (3)

- Finger Allocation
  - Defines the optimal finger delay positions for despreading that maximize the receiver performance (also RX div and SHO)
  - Also eliminates unnecessary changes in the finger time positions between successive allocations
  - Multipath component is kept on the same RAKE finger as long as possible to maximize the performance of channel estimation and maximal-ratio combining
  - In the finger allocation procedure also the shape of the channel impulse response is taken into account when defining the optimum finger delay positions
  - Chip rate of 3,84 MHz offers about 260 ns RAKE finger allocation resolution -> better multipath combining than in IS-95
  - Allocation frequency in normal operation mode is one allocation for a code channel in every 25 ms (accuracy of ¼ chip)
  - Code tracking with accuracy of 1/8 chip is further used in RAKE fingers to track and compensate small delay deviations in multipath component timing (UE movement, TX timing)

RAKE Receiver in WCDMA System (4)

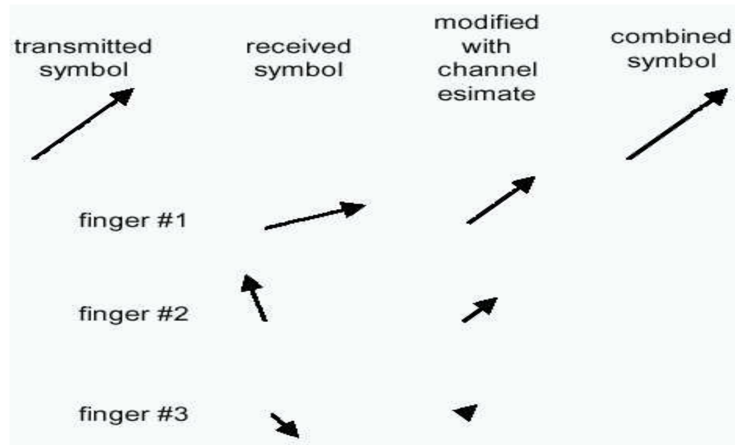
- Finger Descrambling and Despreading
  - The despreading operation for DPDCH (Dedicated Physical Data Channel) and DPCCH (Dedicated Physical Control Channel) is performed in RAKE fingers to recover the receiver wideband signal to symbol level information
  - Multiplying of incoming signal by complex conjugate of scrambling code and channelization code and accumulating the results over symbol periods
  - In the base station receiver 8 fingers are allocated for each code channel (i.e. 8 multipath components can be despread for a single user)
  - Code tracking is used to track and compensate small deviations in multipath component delays i.e. the Code tracking performs the fine adjustment of the delay used in the despreading
  - Tracking for every finger with accuracy of 1/8 chip (32,5 ns)
  - Delay updating by code tracking is performed once in each or every second 10 ms radio frame

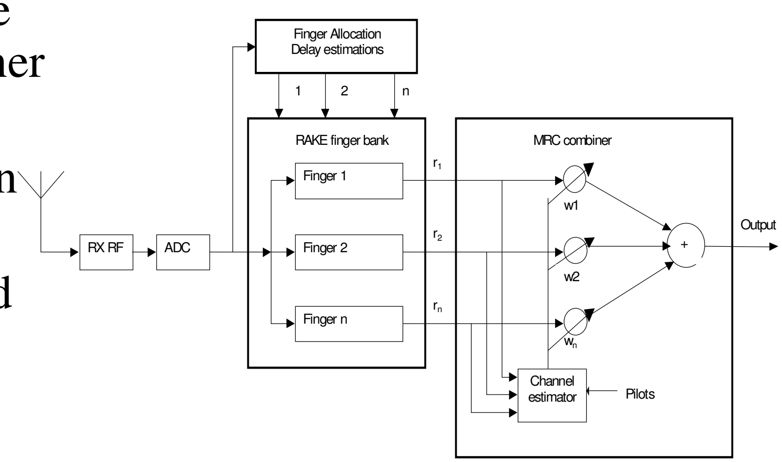
RAKE Receiver in WCDMA System (5)

- Adaptive Estimation
  - Goal is to estimate the characteristics of the time-variant channel
  - In WCDMA the solution is Pilot Symbol Aided + adaptive filtering
  - Is used to remove distortion caused by radio channel and it is based on the known pilot symbols on DPCCH
  - Filter adapts to the Doppler power spectrum (both frequency and the shape of the spectrum)
  - The estimation is done for each finger separately
  - The use of adaptive filter ensures good performance in all kind of propagation conditions
  - In the case of multiple receiver antennas the performance of channel estimation is further improved by combining the power spectrum information available from different receiver antennas
  - The combining process is based on maximal-ratio combining, which decreases the effect of additive noise, which can further be decreased by channel decoding

RAKE Receiver in WCDMA System (6)

- Maximal-Ratio Combining (MRC)
  - Is the optimal form of diversity combining because it yields the maximal SNR achievable
  - It requires the exact knowledge of SNRs as well as the phases of the diversity signals
  - The output symbols from different RAKE fingers are multiplied with complex conjugate of the channel estimate and the result of multiplication is summed together into the “combined” symbol
  - QPSK in WCDMA carries information in phase
  - MRC corrects channel phase rotation and weights components with amplitude estimate





Conclusions

- RAKE receiver attempts to collect the time-shifted versions of the original signal by providing a separate correlation receiver for each of the multipath signals
- RAKE receiver uses several baseband correlators to individually process several signal multipath components
- The correlator outputs are (MRC) combined to achieve improved communications reliability and performance
- RAKE receiver is used in CDMA based systems such as IS-95 and WCDMA

References

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Homework

1. Explain shortly the basic functions in a RAKE receiver.

2. How many fingers can a Mobile Station RAKE receiver's matched filter or "searcher" allocate from a following multipath tapped delay line channel in WCDMA and IS-95 systems? Don't guess!

Tap	**1**	**2**	**3**	**4**	**5**	**6**
Avg. power (dB)	0	-1,5	-6,0	-4,5	-9,0	-15,5
Relative delay (ns)	0	310	500	1090	2430	2510