HomeRF Technology - SWAP

Shared Wireless Access Protocol

HomeRF Technical Goals

- Low cost and voice support of DECT
  - Adapted to 2.4GHz band
  - Client call services well defined
- TCP/IP support of IEEE 802.11
  - Relaxed specs to lower cost
  - Use existing 2.4GHz support (FH)
  - Eliminate complex parts of protocol (PCF & CTS/RTS) to lower cost

Low Cost, Availability, and Technical Features are Keys to Success

HomeRF Origins

Both Data & Voice are Important for HomeRF

SWAP

- HomeRF SWAP spec
  - Designed for both data & voice wireless communication
  - Defines interoperation of PSTN & Internet
- Operates in the 2.4GHz band
  - Uses digital frequency hopping spread spectrum radio
- Derived from extensions of existing cordless telephone (DECT) & wireless LAN technology
  - Enables new class of home cordless services

IP Data at up to 2Mbps & Supports Cordless Telephony

SWAP Supports

- TDMA
  - Time Division Multiple Access
  - Provides delivery of interactive voice & other time-critical service
- CSMA/CA
  - Carrier Sense Multiple Access/Collision Avoidance
  - Service for delivery of high speed packet data

SWAP

- Developed & optimized
  - Meet unique consumer needs at home & SOHO
  - Powerful combination of data & voice capabilities
- Ensure interoperability among SWAP products
  - Backed by major industry companies
  - HomeRF group is working with Home PNA and other organizations to deliver interoperability with complimentary home networking solutions

Capabilities of HomeRF

- Up to 150 foot range
- Networks up to 50 PCs
- Work with dial-up, DSL, and cable modems
- Work through walls & floors
- Data secured through unique network ID
- Robust & reliable & minimizes the impact of radio frequencies
- Includes support of near line quality voice & full telephony

Performance

- Designed to meet the performance demands of available applications
- Product performance will easily enable a user to simultaneously
  - Browse the Internet
  - Print a web page
  - Listen to music

Technical Summary

- Hybrid TDMA/CSMA frame
  - Beacon from Connection Point (CP) sets frame structure
- Frequency Hopping: 50 hops/sec
- Range up to 50 meters indoors
- Speed: dual speed
  - 2 or 4 FSK Yields 1 or 2 Mb/sec
  - Also supports TCP/IP voice
- Voice: High quality voice channels with retransmission
  - High quality cordless telephones
  - Voice recognition

Technical Summary - Data

- Handles data like IEEE 802.11
- Relaxed PHY specs from IEEE 802.11
  - Lowers radio cost significantly
  - Same hop sequences
    - Localized for France, Spain, Japan, US, EC
    - Different bandwidth for Japan, France, Spain
- Manages isochronous traffic
- Simplified protocol
- Comparable backoff, packet structure, ad-hoc capabilities

Technical Summary - Voice

- Handles voice like DECT with retransmission
- Uses DECT calling stack
- Uses DECT A/B fields
- 32kb/s ADPCM (Adaptive Differential Pulse Code Modulation)
- 20ms Frames - retransmit in beginning, outbound at end (better for data)
- Interleaved up and down link packets

Data Service Types

- Isochronous (I Node)
  - Circuit switched & connection-oriented
  - Used mainly to carry interactive voice
    - Minimum latency
    - Requires the presence of a Connection Point
  - Example: cordless telephones
- Asynchronous (A Node)
  - Packet switched & connectionless
  - Used for data networking - TCP/IP traffic
  - Example: fridge pad
- I Nodes get priority on bandwidth

Data Service Types

- CP - connection point
  - Can manage a network or act as an A node
  - Can be USB, PCI, PC-Card, Device Bay
  - CP can place calls even when PC is down

Voice in HomeRF

What is DECT?

- Digital Enhanced Cordless Telecommunications
- Target applications
  - SOHO voice and data
    - Residential cordless
  - Wireless enterprise systems
  - Fixed wireless systems with range up to 15km

DECT Market

- It is one of the world's most successful cordless voice standard
  - Over 45 million DECT terminals in use*
  - Installed base of 200 million units forecast by 2003*
  - Growing supplier base: over 200 today*
- DECT is a worldwide solution
  - Accepted over 110 countries worldwide
  - Long-term spectrum availability
  - More countries are accessible through the 2.45 GHz ISM frequency band

* - Source: Siemens

Elements of High Quality Cordless Voice

- Expectation of the audio path
  - Wire-line audio clarity
  - Void of pops, clicks, echoes or delays
  - Functions with other telephony appliances
- Expectation of mobility and range
  - Wander anywhere within the residence
  - And to the mailbox and the pool
  - And some expect to go to the neighbor's home!
- General expectations of mobile voice devices
  - Several days of standby and 10 or more hours of talk
  - Easy and intuitive to operate

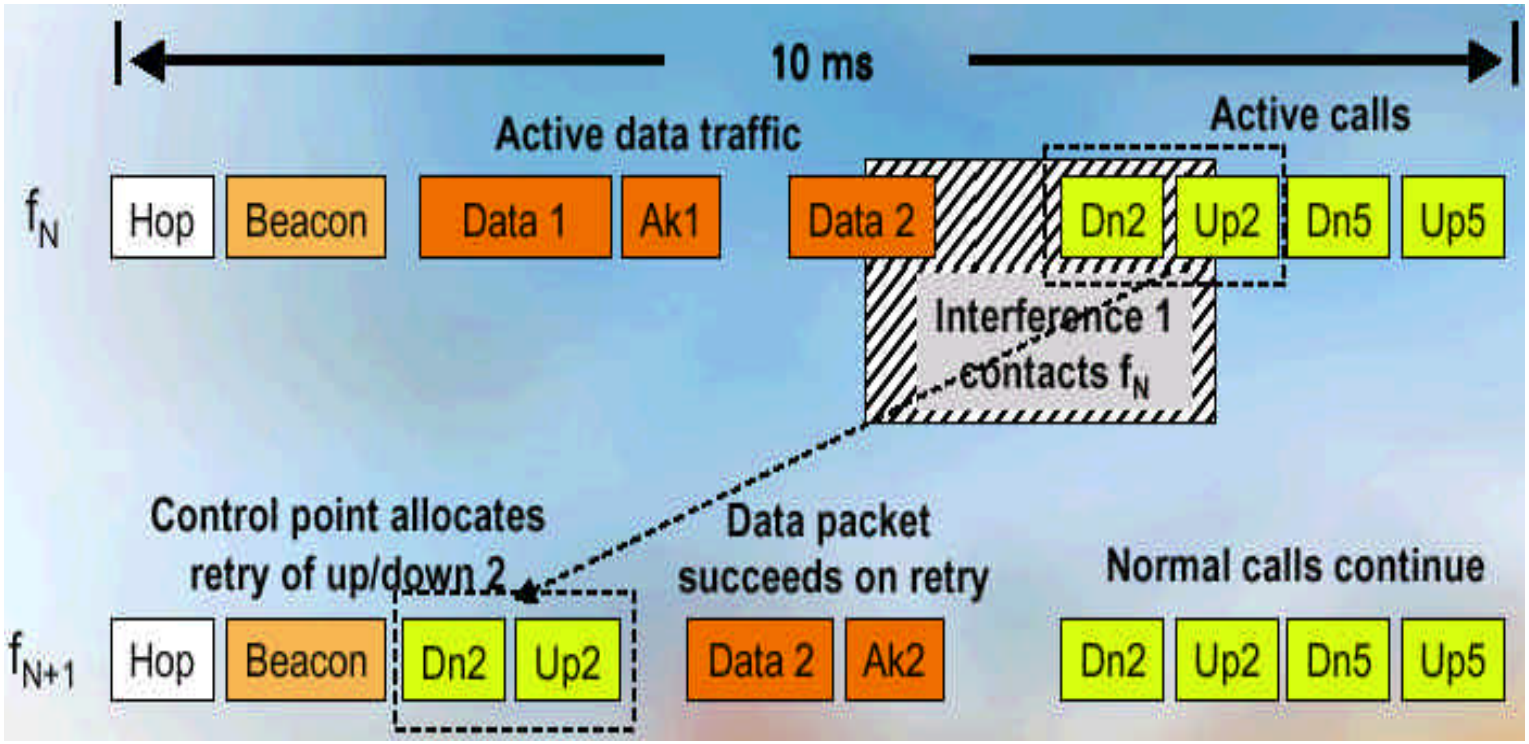
Major Threats to Cordless Voice Quality

- Speech encoding & modulation technique
  - Efficient conversion of speech to digital format
  - Guaranteed maximum transmit and processing delay
- Bit errors and packet errors
  - Detect and repair, or retransmit
- Interference from other RF emitters
  - Avoid or recover

Threats to Cordless Voice Quality Due to Latency

- Latency is caused by the round trip transmit times
  - Between base station/access points and handset/NIC
- Latency is a function of the size of the frames transmitted
  - Voice is best served by short frames
  - Data is best served by longer frames
- Latency is a function of the channel access method
  - Interference probability increases with frame size
  - Contention methods are undesirable for real time applications like voice
  - High priority, guaranteed periodicity is optimal for voice

HomeRF Minimizes Latency to Voice Data Even in the Presence of Interference

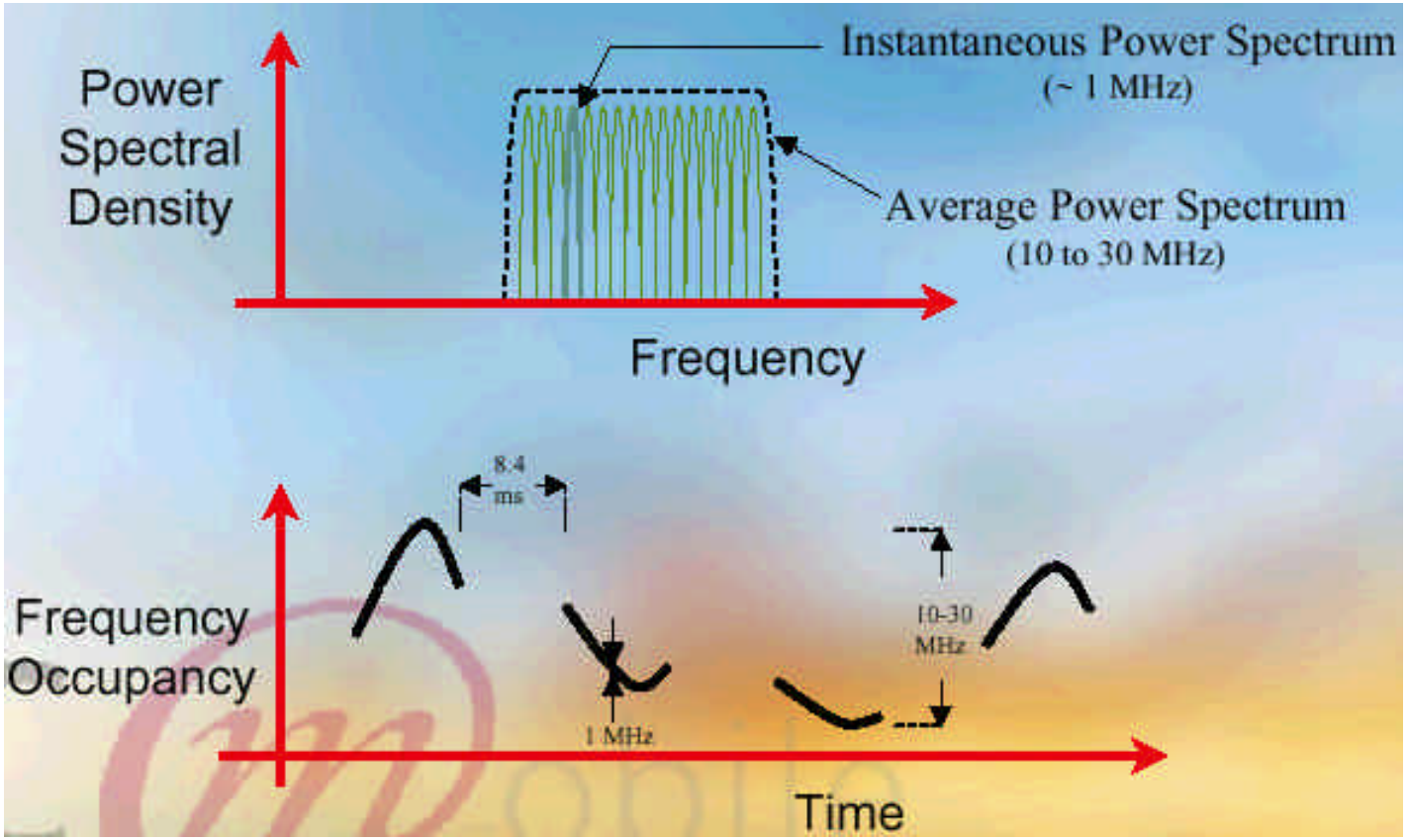


Source: Siemens

Microwave Ovens Are a Common Source of Interference

- Nominal 2450- MHz center frequency
- Approximately 50% duty factor
  - 8.4- ms on- time in US
  - 10- ms on- time in Europe
- Instantaneous narrowband, but “wandering”
  - 1- MHz short- term spectral width
  - 1- to 3- MHz chirp, probably magnetron self- heating
  - 10-30 MHz average occupancy due to “mode stirring”
- Relatively intense
  - Avoidance yields most effective mitigation
  - Linear processing of marginal value

Spectral/Temporal Characteristics of Microwave Ovens



Source: Siemens

HomeRF Mitigates the Effects of Microwave Ovens

- Probability of a hit by microwave oven interference
  - 20% of the band for 50% of the time
- HomeRF uses time/frequency diversity to reduce probability
- HomeRF uses hopset adaptation for persistent interferers

Consumer Benefits of HomeRF for Residential Cordless Voice Networks

- Provides mobility throughout the home or small office
- Extremely high quality voice suitable for home or business
- Security against eavesdropping
- Multi-user capabilities capitalizes on household trends
- Extensive core feature set beneficial to residence & SOHO
- Meets price point expectations

Technical Advantages of HomeRF for Residential Cordless Voice Networks

- Audio Clarity is achieved by
  - Use of Adaptive Differential Pulse Code Modulation
- Latency is minimized by
  - Utilizing 10ms frame length when voice is active
  - Providing high priority isochronous channels for voice

Technical Advantages of HomeRF for Residential Cordless Voice Networks

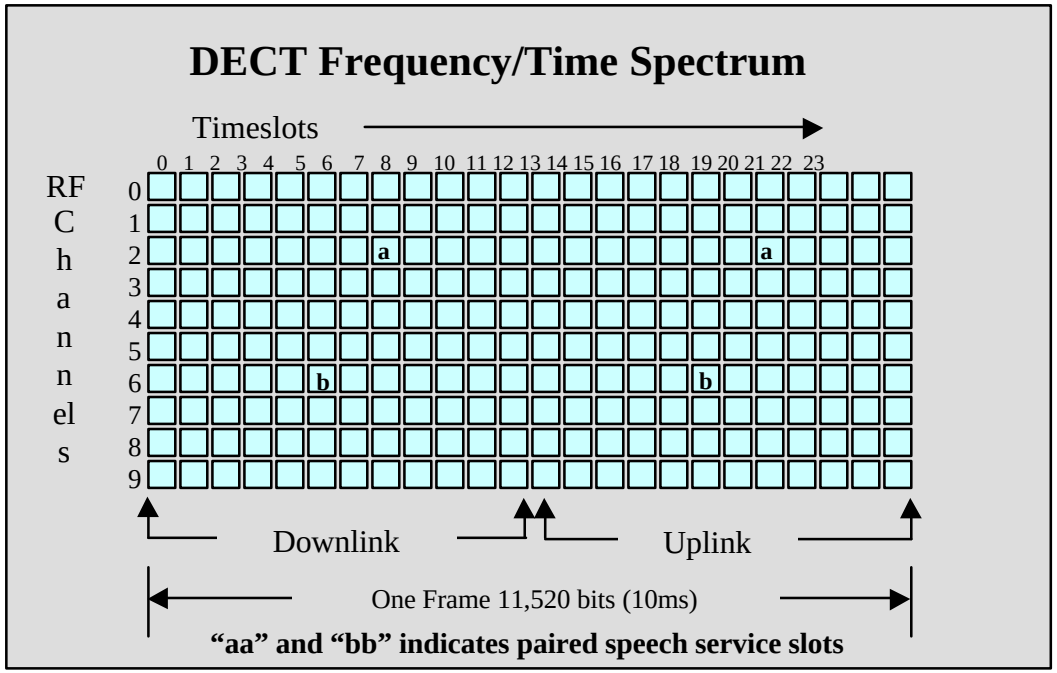
- Bit and frame errors are reduced by
  - Active interference avoidance
  - Time/Frequency diversity by re-transmitting the frame
- Interference is mitigated in HomeRF by
  - Re-transmitting lost data in the very next frame
  - Hopping to a new frequency each frame
  - Modifying the hopset to hop around the interferer

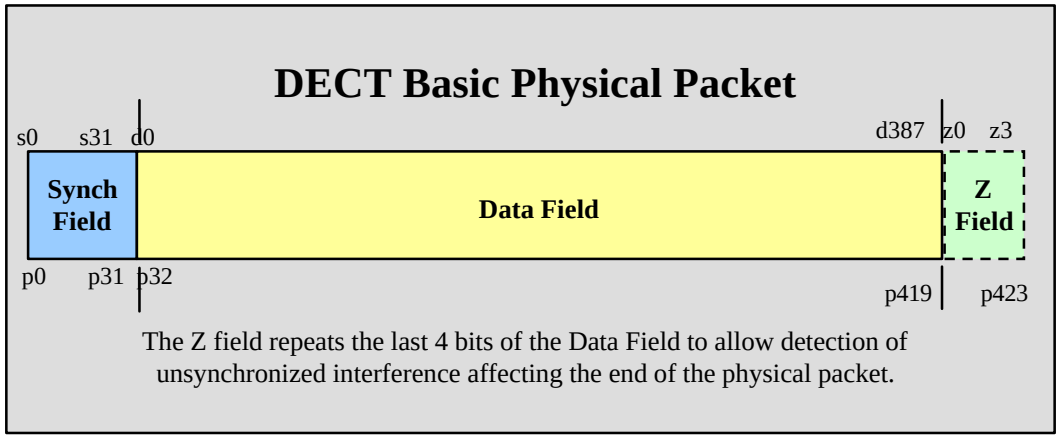
ADPCM

Adaptive Differential Pulse Code Modulation

- Coding technique optimized for human voice spectrum
  - Carefully designed around ‘what we hear’
- Optimal tradeoff between BW and Quality
  - Bit rate scheme is optimized for clarity
  - 32 Kbps is efficient use of radio spectrum
- ADPCM rates high on subjective listening tests
  - Mean opinion scores are on a scale of 1- 5 (5 is highest)
  - Land-line at 64Kbps produces an MOS of 4.3
  - ADPCM at 32Kbps produces an MOS of 4.1
  - Digital cellular at 8Kbps produces an MOS of 3.4
- Near land-line quality

DECT


DECT Frequency/Time Spectrum
Timeslots
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
RF Channels
0
1
2
3
4
5
6
7
8
9
a
a
b
b
Downlink
Uplink
One Frame 11,520 bits (10ms)
"aa" and "bb" indicates paired speech service slots


DECT Basic Physical Packet
s0
s31
d0
d387
z0
z3
Synch Field
Data Field
Z Field
p0
p31
p32
p419
p423
The Z field repeats the last 4 bits of the Data Field to allow detection of unsynchronized interference affecting the end of the physical packet.

DECT Features

- Features
  - Supports data, voice, and video
  - 1.152 Mbps data rate
  - High network capacity
  - 1.88-1.90 GHz frequency band
  - Available now
- Access/Modulation
  - TDMA/GFSK

DECT
Advantages & Disadvantages

- Advantages
  - ETSI sanction
  - Coexistence with 2.4 GHz LANs
- Disadvantages
  - Lower speed

Data in HomeRF

PHY Features

- Nominal 100 mW transmit power
- Minimum receiver sensitivity of -76 dBm (2FSK)
  - Range >50 m in typical homes
  - -85 dBm typical sensitivity
- Cost effective filter requirements
  - Use MAC to reduce PHY cost
  - Makes single-chip integration simpler

FH - Frequency Hopping

- It works very much like its name implies
  - Frequency hopping
    - Data signal is modulated with a narrowband carrier signal that hops from frequency to frequency as a function of time over a wide band of frequencies
    - Relies on frequency diversity to combat interference
      - This is accomplished by multiple frequencies, code selection & FSK
  - E.g., A FH radio will hop the carrier frequency over the 2.4GHz frequency band between 2.4GHz & 2.483GHz
    - If the radio encounters interference on one frequency, the radio will retransmit the signal on a subsequent hop on another frequency

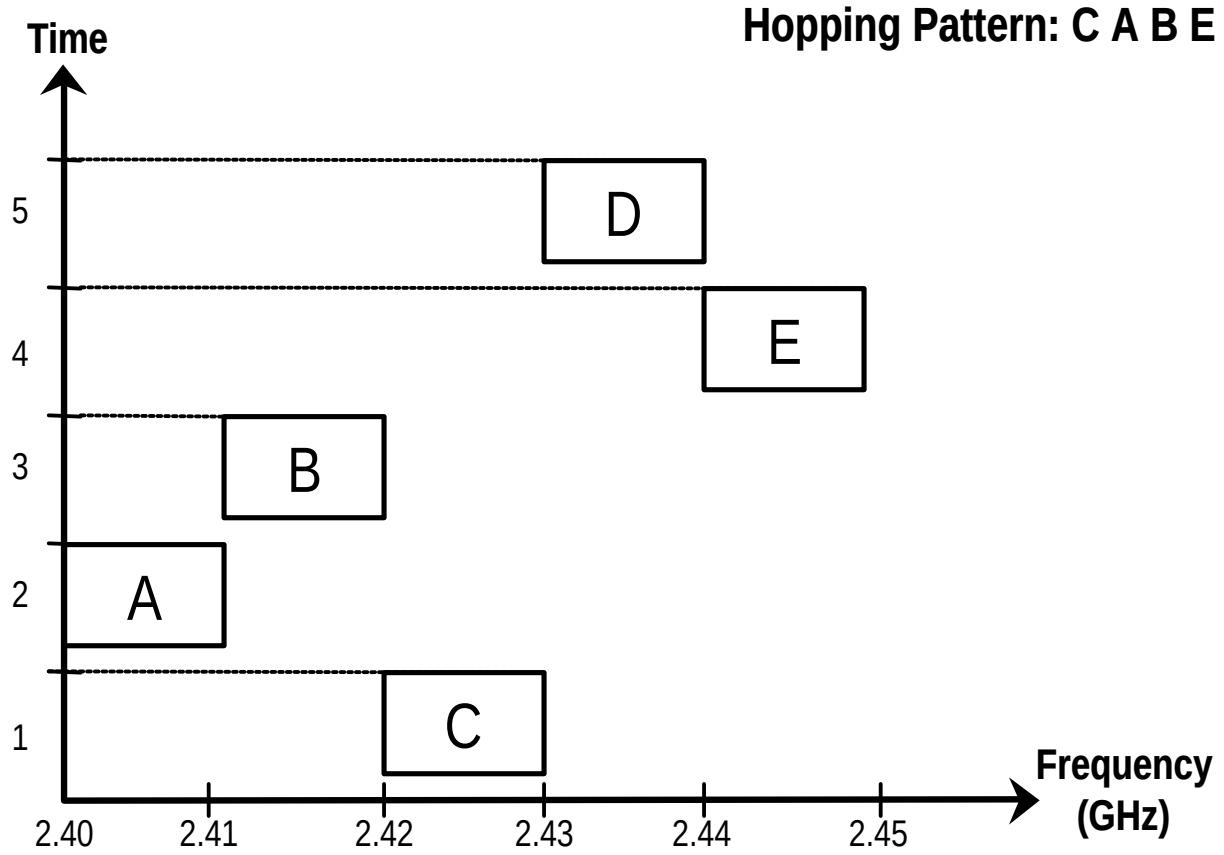
FH Technology

- Hopping code determines the frequencies the radio will transmit and in which order
  - Hopping pattern is known to both transmitter & receiver
    - To properly receive the signal the receiver must be set to the same hopping code & listen to the incoming signal at the right time & correct frequency
  - If properly synchronized the net effect is to maintain a single logical channel
- Unintended receiver see FH to be short-duration impulse noise

FH Technology

- FH system must hop its whole information signal over a band of frequencies of the ISM band in use
  - Does not interfere with primary user
- Because of the nature of its modulation technique frequency hopping can achieve up to 2Mbps data rates
  - Faster data rates are susceptible to huge number of errors
- Frequency hopping technique reduces interference
  - An interfering signal from a narrowband system will affect the spread spectrum signal only if both are transmitting at the same frequency at the same time
  - Aggregate interference will be very low, resulting in little or no bit errors

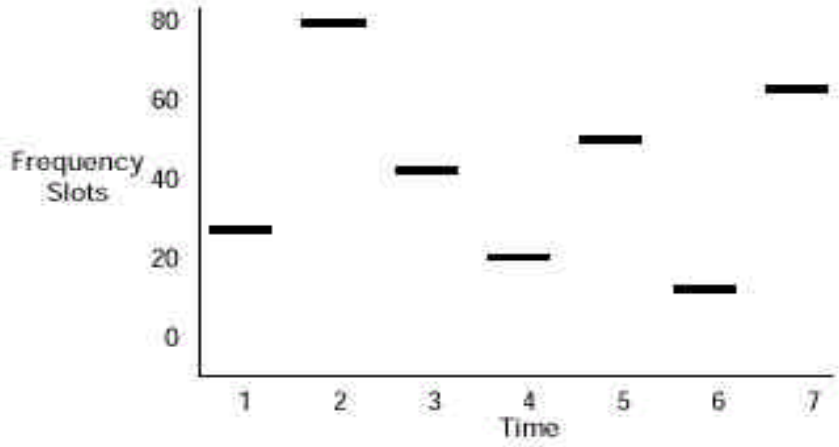
FH Example



With FH, the Carrier Frequency Changes Periodically - The incoming digital stream is shifted in frequency by an amount determined by a code that spreads the signal power over a wide bandwidth

FH Example for One Channel

- 7 frequency slots exist in the band
  - System send the information signal in frequency slot 24 for the first time slot, then frequency slot 78 for the second time slot, then frequency slot 42 for the third time slot, and so on
- Users wishing to receive signals must tune receiver to particular frequency slot
  - To receiver channel number 1 must tune its receiver to frequency slot 24 for first time slot, frequency slot 78 for the second time slot, then frequency slot 42 for the third time slot, and so on



Different FH Pattern

- Each channel is a different frequency hopping pattern
  - Channels are distinguished between channel 1 & channel 2 by having a different frequency hopping pattern
  - Receiver of channel 2 must hop his receiver according to the channel 2 FH pattern
  - This is not a different frequency as in Frequency Division Multiplexing - it is a different Frequency Hopping Pattern
    - In FDM each channel simply stays on one frequency slot for the duration of the transmission

Different FH Pattern

- It is possible to have operating radios use spread spectrum within the same frequency band & not interfere
  - Such that they use a different hopping pattern
  - While one radio is transmitting at one particular frequency the other radio is using a different frequency
    - A set of hopping codes that never use the same frequencies at the same time are considered orthogonal

FH PHY Layer

- Has 22 hop patterns to choose from
- Frequency hop physical layer is required to hop across the 2.4 GHz ISM band covering 79 channels
- Each channel occupies 1MHz of bandwidth
  - Must hop at the minimum rate specified by the regulatory bodies of the intended country
    - Minimum hop rate of 2.5 hops per second is specified for the US

PHY Layer Header

- Each physical layer uses their unique header
  - To synchronize the receiver & determine signal modulation format & data packet length
- PHY layer headers are always transmitted at 1Mbps
- Predefined fields in headers provide the option to increase the data rate to 2Mbps for the actual data packet

MAC Features

- MAC provides good support for voice & data
- Leverages existing DECT technology for voice
- Excellent integration with TCP/IP networking protocols
  - Easy integration with Ethernet
  - Support broadcast, multicast & fragmenting
- Data security - basic/enhanced levels of encryption
  - Basic: 24-bit Network ID & Frequency Hopping
  - Enhanced: Basic + LFSR algorithm
- Extensive power management for ultra-portable devices

Optimizes Existing Technology for Home Use

What Does the MAC Do?

- Provide access control functions for shared medium PHYs in support of the LLC layer
- MAC layer provides these primary functions
  - Addressing - Accessing the wireless medium
  - Access coordination - Joining the network
  - Frame check sequence generation and checking - Providing authentication and privacy
- MAC layer performs the addressing and recognition of frames in support of the LLC

What Does the MAC Do?

- Accessing the wireless medium
  - CSMA/CA
    - Contention based protocol similar to IEEE 802.3 Ethernet
    - 802.11 specification refers to this mode as distributed coordination function (DCF)
  - Priority based access
    - Contention free access protocol
    - Usable on infrastructure network configurations containing a controller called a point coordinator with the access points
    - 802.11 specification refers to this mode as point coordination function (PCF)

Multiple Access

- Basic access method for IEEE 802.11 is the DCF which uses CSMA/CA
  - Station listens for users
  - If the channel is idle, the station may transmit
  - However if it is busy, each station waits until transmission stops, and then enters into a random back off procedure
    - Prevents multiple stations from seizing the medium immediately after completion of the preceding transmission

The MAC Sub-layer

- MAC specification for 802.11 has similarities to 802.3 Ethernet wired line standard
  - CSMA/CA protocol used for 802.11
    - Uses carrier-sense, multiple access, collision avoidance
    - Avoids collisions instead of detecting a collision like the algorithm in 802.3
    - Collision avoidance is used because it is difficult to detect collisions in an RF transmission network

MAC & PHY Layer Operation

- MAC layer operates together with the PHY layer by sampling the energy over the medium transmitting data
- PHY layer uses a clear channel assessment (CCA) algorithm to determine if the channel is clear
  - This is accomplished by measuring the RF energy at the antenna and determining the strength of the received signal
    - This measured signal is commonly known as RSSI
  - If the received signal strength is below a specified threshold the channel is declared clear and the MAC layer is given the clear channel status for data transmission
  - If the RF energy is above the threshold, data transmissions are deferred in accordance with the protocol rules
  - The standard provides another option for CCA that can be alone or with the RSSI measurement

MAC & PHY Layer Operation

- Carrier sense can also be used to determine if the channel is available
  - This technique is more selective sense since it verifies that the signal is the same carrier type as 802.11 transmitters
- The best method to use depends upon the levels of interference in the operating environment
- CSMA/CA protocol allows options to minimize collisions
  - Using request to send (RTS), clear-to-send (CTS), data & acknowledge (ACK) transmission frames in a sequential fashion

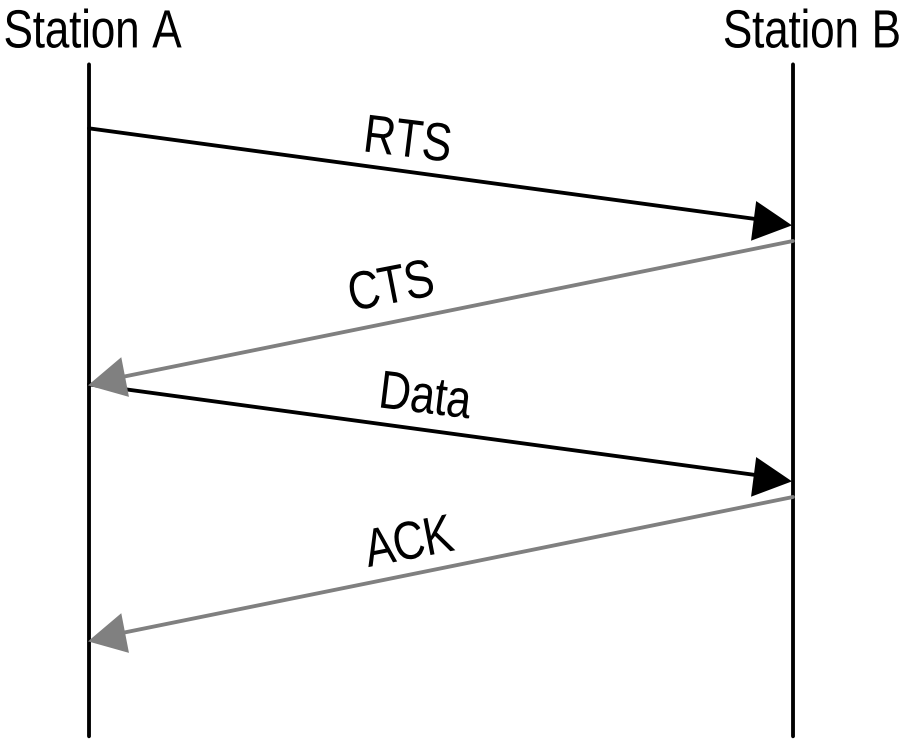
CSMA/CA Protocol Minimizes Collisions

- Communication is established when one of the wireless nodes sends a short message RTS frame
- The RTS frame includes the destination and the length of message
- The message duration is known as the network allocation vector (NAV)
- The NAV alerts all others in the medium, to back off for the duration of the transmission

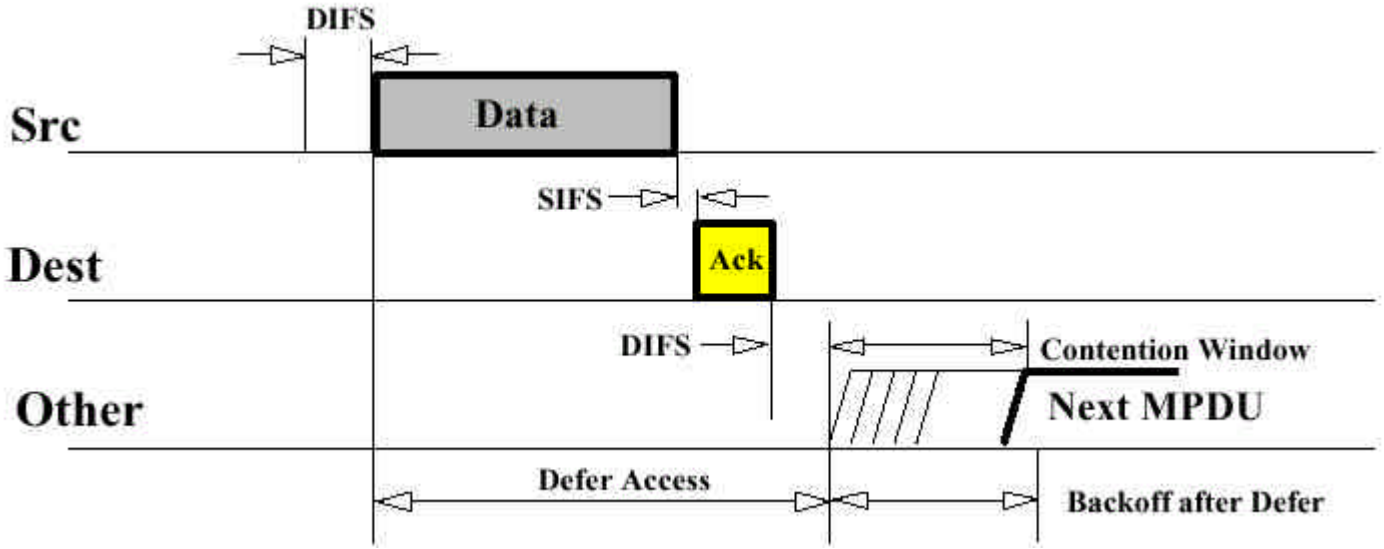
CSMA/CA Protocol Minimizes Collisions

- The receiving station issues a CTS frame which echoes the senders address and the NAV
- If the CTS frame is not received, it is assumed that a collision occurred and the RTS process starts over
- After the data frame is received, an ACK frame is sent back verifying a successful data transmission

RTS/CTS/ACK Protocol



CSMA/CA Back-off Algorithm



- Packet reception in DCF requires acknowledgment
- The period between completion of packet transmission and start of the ACK frame is one Short Inter Frame Space (SIFS)
- ACK frames have a higher priority than other traffic
  - Fast acknowledgement is one of the salient features of the 802.11 standard, because it requires ACKs to be handled at the MAC sublayer

PC Interface

- SWAP's PC connection is designed for use under Windows 98, Windows2000, and beyond
  - Wake on Ring
  - Connection oriented NDIS
  - A nodes appear as Ethernet devices
  - I nodes become Connection Oriented clients

Network Topology
SWAP System Support

- Ad-Hoc Network
  - Only data communication is supported
  - All stations are equal
  - Control of the network is distributed between the stations
- Managed network under the control of a CP
  - Ideal for isochronous data and power savings
    - Such as time critical communications such as Interactive voice
  - Provides gateway to PSTN
  - Can be connected to PC via standard interface such as USB that will enable voice & data services
  - Support power management for prolonged battery life by scheduling device wakeup & polling

Network Topology

- HomeRF networks accommodate - **127** Nodes (max.)
- Nodes can be a mixture of 4 basic types:
  - Connection point that supports both voice & data services
  - Voice terminal that only uses TDMA service to communicate with a Base Station
  - Data node that uses CSMA/CA service to communicate with a base station and other data nodes
  - Voice & data nodes which can use both types of service

Main SWAP System Parameters

Main System Paramters	HomeRF - SWAP
PHY Layer - Frequency Hopping/Direct Sequence Range	2.4GHz Frequency Hopping ISM band
Frequency Hopping Network (hops per second) Radio	50, less reliable than Bluetooth
Optimized for	Voice & Data
Real data rate	1Mbps using 2FSK modulation, 2 Mbps using 4FSK modulation; Standard 800kbps rate for Isochronous & Asynchronous data, Optional 1.6Mbps rate for Asynchronous data
Near-line quality voice links/channels	4
Device links per base	Unlimited
Encryption Routine	Blowfish
Bridge Range	100 meters
Transmission Power	100mW
Power Management	Both A-nodes & I-nodes can achieve power savings using power management services of a CP
Range	Covers typical home & yard
Supported stations	Up to 127 devices per network
Voice connections	Up to 6 full duplex conversations
Data Security	Blowfish encryption algorithm (over 1 trillion codes)
Data Compression	LZRW3-A algorithm
48-bit Network ID	Enables concurrent operation of multiple co-loacted networks

Interoperability with HomePNA

- HomeRF Products Work With HPNA-based Products
  - TCP/IP is used in HPNA based products
    - HomeRF products fully support TCP/IP
  - Consumer requires a bridge
    - Interface to connect phone line network to wireless HomeRF network
    - SWAP spec defines this bridging
    - Vendors are developing future bridging products

Interoperability with Bluetooth

- Bluetooth
  - Technology to connect devices without wires
  - Provide short-range connections between mobile devices & to Internet via bridging devices to different networks
  - Provide Internet capability
- HomeRF SWAP
  - Wireless technology optimized for home
  - Data networking & dial tones between devices like PCs, cordless phones, web tablets, broadband cable & DSL modem

Interoperability with Bluetooth

- Full Bluetooth & HomeRF functionality can be implemented Within one device
- Frequency spectrum is shared without interference when operating in the same space
- Both technologies might coexist
  - E.g.; Bluetooth enabled handheld PDA may be need to synchronize addresses between the PDA and home PC based mail lists

Examples of SWAP Products

- Set up a wireless home network
  - Share voice & data between PC's, peripherals, PC-enhanced cordless phones & new devices such as portable, remote display pads
- Access the Internet from anywhere in and around the home from portable display devices
- Share an ISP connection between PC's and other new devices
- Share files/modems/printers in multi-PC homes

Examples of SWAP Products

- Intelligently forward incoming telephone calls to multiple cordless handsets, FAX machines & voice mailboxes
- Review incoming voice, FAX & e-mail messages from a small PC-enhanced cordless telephone handset
- Activate other home electronic systems by simply speaking a command into a PC-enhanced cordless handset
- Multi-player games and/or toys based on PC or Internet resources

Companies Developing SWAP Products

- Butterfly Communications
- Cayman Systems
- Compaq Computer Corp.
- Hewlett Packard
- IBM
- Intel
- iReady
- Microsoft
- Motorola
- Proxim
- OTC telecom
- RF Monolithics
- Samsung
- Symbionics