



Performance of a Very Low Power Wireless Protocol

Joshua L. Jabs
C. Hwa Chang
Robert Tingley

Presented by Natthapol Pongthaipat



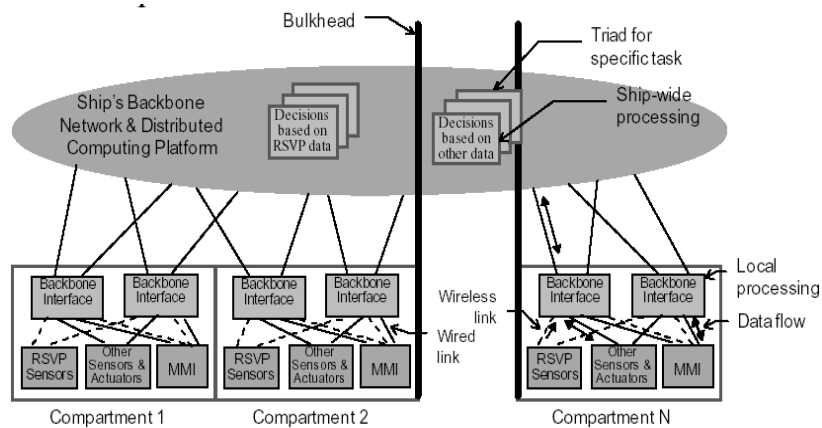
Outline

- Introduction
- Data Transmission in IEEE 802.11
- Data Transmission in RSVP
- Power Calculation and Comparison
- Conclusion

Introduction

- IEEE 802.11 falls short in low power requirement of applications
- In 1998, U.S. Navy “Reduced Ships-Crew by Virtual Presence” (RSVP) research program
- To Develop infrastructure network with multiple mobile and fixed sensors to wirelessly communicate with a ship’s wired backbone

RSVP Architecture





RSVP Requirements

- Sensors must operate for a period of 10 years without battery replacement
- Average time between uplinks = 15 min. with 1 s minimum capability
- Max time between downlinks = 100 s
- Max environmental raw data size = 30 bytes
- Min sensors per access point = 90 sensors
- Max bit error rate (BER) = $10e-5$
- Battery power available = 4.5V@2850 MAH



Data Transmission in IEEE 802.11

- Three physical specifications
 - Diffused infrared pulse position (IR)
 - Direct sequence spread-spectrum (DSSS)
 - Frequency hop spread-spectrum (FHSS)
- Cost efficient infrared applications are limited to fixed sensors operating distances ≤ 3 feet
- Limited discussion to DSSS and FHSS at 1 Mbps



DSSS Power requirements

- Assumptions
 - Channel is slow
 - No Doppler effect
 - Gaussian noise distribution
 - MAC layer eliminates multi-user interferences

- Signal transmitted by user k is

$$S_k(t) = \sqrt{\frac{2E_s}{T_s}} m_k(t) p_k(t) \cos(2\pi f_c t + \phi_k)$$

- Received ith bit of user 1 is

$$Z_i^{(1)} = \int_{(i-1)T+\tau_1}^{iT+\tau_1} r(t) p_1(t - \tau_1) \cos(2\pi f_c (t - \tau_1) + \phi_1) dt$$



DSSS Power requirements (cont.)

$$Z_i^{(1)} = I_1 + \sum_{k=2}^N I_k + \xi$$

$$I_1 = \int_0^T S_1 p_1(t) \cos(2\pi f_c t) dt = \sqrt{\frac{E_s T}{2}}$$

where I_1 = desired signal

I_k = other signals

ξ = noise

From Gaussian noise distribution,

$$\xi = \int_0^T n(t) p_1(t) \cos(2\pi f_c t) dt$$



DSSS Power requirements (cont.)

I_k are signals from all other stations. Use central limited theorem, average probability of bit error is

$$P_{be} = Q \left(\frac{1}{\sqrt{\frac{K-1}{3N} + \frac{N_0}{2E_b}}} \right)$$

Since only single transmitter use the medium at any given time, average probability of bit error is reduced to that of BPSK

$$P_{be} = Q \left(\sqrt{\frac{N_0}{2E_b}} \right)$$



DSSS Power requirements (cont.)

- Assume path gain is Rayleigh distributed

$$P_e = \int_0^{\infty} P_e(X) p(X) dX$$

where $P_e(X)$ is from specific modulation scheme

X is signal-to-noise ratio, $X = \alpha^2 E_b / N_o$

$p(X)$ is pdf of X due to fading

$$p(X) = \frac{1}{\Gamma} \exp\left(-\frac{X}{\Gamma}\right) \quad \text{where} \quad \Gamma = E(\alpha^2) E_b / N_o$$

Probability of error for DSSS/coherent BPSK is

$$P_e = \frac{1}{2} \left[1 - \sqrt{\frac{\Gamma}{1 + \Gamma}} \right]$$



FHSS Power requirements

- Assuming AWGN, slow-FHSS and fast-FHSS have the same performance
- Assume slow-FHSS at 1 Mbps (BFSK is defined by 802.11)
- Use BER of non-coherent FSK

$$P_e(X) = \frac{1}{2} \exp\left(-\frac{E_b}{2N_0}\right)$$



FHSS Power requirements (cont.)

Put P_e of non-coherent FSK into

$$P_e = \int_0^{\infty} P_e(X) p(X) dX$$

With $p(X)$ equals to pdf of Rayleigh fading,


Probability of error for FHSS/BFSK in AWGN with Rayleigh fading channel

$$P_e = \frac{1}{2 + \frac{E_b}{N_0} \bar{\alpha}^2}$$



802.11 MAC

- 802.11 MAC specifies two functions
 - Distributed Coordination Function (DCF)
 - Point Coordination Function (PCF)
- In normal load, PCF is most suitable for RSVP to meet requirements
- In high load, DCF will be utilized
- Power saving
 - 802.11 performs virtual carrier sensing using Network Allocation Vector (NAV)
 - Stations can enter sleep mode



B. Data Transmission (On-Time) in RSVP (1)

- Reduced Ships-Crew by Virtual Presence (RSVP) was designed to work with specific radio architectures resulting in the elimination of MAC/PHY convergence sublayer.
- Sensors in RSVP can communicate only with the AP and work through a slotted TDM scheme instead of AP polling as in 802.11 PCF.
- RSVP emphasizes on the following four main requirements,
 - Low power
 - High reliability
 - Adaptability under loaded conditions
 - No preference to sensor data or sensor requests based on location.



B. Data Transmission (On-Time) in RSVP (2)

- Non-coherent FSK modulation is used in the 2.4 GHz range.
- RSVP requires at least 17 dB SNR to properly detect the signal.
- It operates at 200 kbps RF channel.
- The protocol time division multiplexes each AP channel (single frequency) into 111 slots as show in figure () which make up one APCM/SC (Access Point Controller Module/Sensor Cluster) cycle.



B. Data Transmission (On-Time) in RSVP (3)

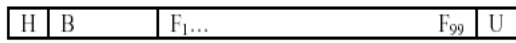


Figure 2: APCM/SC Cycle Division

H: Access Point Sync Frame
B: Bandwidth on Demand Block (slots 1- 10)
F: Normal Sensor Frame (slots 11 - 109)
U: Unused

- The frame configuration allows for a maximum of 99 Sensor Clusters (SCs) per AP.
- H frame is used for AP and SC synchronization purpose.
- The B block is used by AP for larger data transmissions.
- By listening to H frame, a new SC can determine the availability of B block. When granted the access, SC will be assigned with a slot number (11 - 109). Any ready data ready can be transmitted on this slot.



B. Slot Assignment Methodology

- Each AP can support up to 99 SCs.
- The slots are assigned during the configuration process.
- Slots are initially assigned one slot apart to conserve power due to the more SC's idle time.
- After AP reaching 50 SCs, any new request by SC will be turn down. SCs that are still unable to find other AP have to establish a connection via emergency request.



B. SC Listening Offset

- For a lenient sync, each SC must turn on its power every 100s.
- SC will be assigned a specific synchronization time based on the overall AP time (a continuous repeating sequence broadcast in the H frame running from slot 11 - 110).
- For example, if SC is assigned slot 45, it will wake up during every AP time 45.
- Each SC will discover the AP failure at a minimum of one second apart giving available AP the same interval of one second to grant new access.



B. APCM/SC Packet Transmission

- H frame is used to carry the APCM/SC packet.
- The APCM/SC packet is used to
 - grant new access to SCs (AP)
 - kick off SCs currently on the channel (AP)
 - manage bandwidth on demand (B block) (AP)
 - synchronization (SC)
- There are two types of SC's transmission
 - data transmission to AP using F frame (basis for power analysis).
 - requesting new access and the transmission during B block. (will not be a factor for total power requirements)



Power Calculation And Comparison (1)

- The total power is $= S + P_s + P_p + (R + T)$
- Ignoring the power used in gathering and processing environment (S and P_s).
- Receiver power - R is included in the power used in processing protocol P_p .
- We mainly focus on the transmitted power T consisted of,
 - t_t = average time spent transmitting derived from the MAC protocol and RSVP
 - P_t = average transmitted power

Power Calculation And Comparison (2)

- For 802.11 DSSS

$$t_t = \frac{\# \text{ of Bytes}}{\text{TransmissionRate}} = \frac{82 \text{ Bytes} * \frac{8 \text{ bits}}{\text{Byte}}}{\frac{1 \text{ Mbit}}{s}} = 656 \mu\text{s}$$

- For 802.11 FSSS

$$t_t = \frac{58 \text{ Bytes} * \frac{8 \text{ bits}}{\text{Byte}} + 129 \text{ bits}}{\frac{1 \text{ Mbit}}{s}} = 593 \mu\text{s}$$

- For RSVP

$$t_t = \frac{30 \text{ Bytes} * \frac{8 \text{ bits}}{\text{Byte}} + 146 \text{ bits}}{\frac{200 \text{ Kb}}{s}} = 1.93 \text{ ms}$$

Power Calculation And Comparison (3)

- Measurement was carried out in one of the main engine rooms, where the amount of machinery increases the multipath effects.
- Rayleigh fading parameter is found from the time average value of the simulation data.
- Noise level is found to be = -117 dBm resulting in 6.3 mW/bit and 25.2mW/bit power requirement for DSSS and FSSS to obtain BER = 10⁻⁵ respectively.

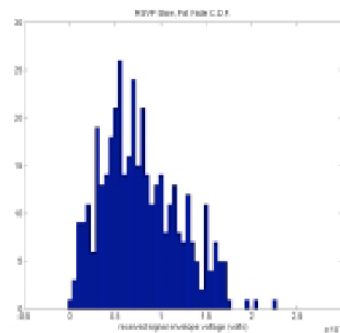


Figure 3. Histogram of Propagation Measurement



Power Calculation And Comparison (4)

- For RSVP, using FSK modulation, AP is able to change its operating frequency based on the RSSI of each of its SC, thus the author assumes that there will be no multipath effect and only LOS communication between SC and AP is considered.
- For 17 dB SNR margin, the resulting necessary transmission power for RSVP is 1mW.
- To account the power used in the creation and modulation of the signal and protocol handling, from table 2, the required transmitted power increase from,
 - 6.3 to 214 mW for DSSS
 - 25.2 to 720 mW for FSSS
 - 1 to 69 mW for RSVP



Power Calculation And Comparison (5)

Table 2. Common SS Characteristics

Manufacturer	Product	Tx	Rx	Sleep	Modulation
Nokia	C020 WLAN CARD	1.7W to tx at 100mW	1.3 W	.1W	DSSS
Aironet	PC4800B	2 W to tx at 30mW	1.5 W	.05W	DSSS
Instersil	PRISM DSSS PC Card	2W to tx at 56mW	1.5 W	NA	DSSS
Symbol	Spectrum 24 WLAN	2W to tx at 100mW	1.5 W	.015 W	FHSS
Intermec Technologies	2125 OpenAir PC Adapter	1.5W to tx at 100mW	.75 0W	.01W	FHSS
Aironet	LM3100	900mW to tx at 63mW	1.2 W	.015 W	FHSS



Power Calculation And Comparison (6)

- Synchronization is done in every 100s (beacon messages).
- Poll request and acknowledgement sent by AP during transmission once every 15 minutes.
- Every receive mode requires about 1W as shown in table 2.
- For 802.11, beacon message is 92 bytes long and would take 736 microsec to received (at 1 Mbps).
- ACK message is 14 bytes and would take 112 microsec to received (at 1 Mbps)
- No ACK is required for RSVP, and the average beacon message length is 18 bytes which would take 990 microsec and 129 mw to received (at 200 kbps)
- Sleep mode power consumption for 802.11 is 15 mw compared to 0.1 mW for RSVP (why ???).



Power Calculation And Comparison (7)

- Total life span of each system

$$\frac{2850mAh * 4.5V * .000114 \frac{years}{hour}}{TotalPower\ cycle * Cycle\ sin\ a\ year} = \# \text{ of years}$$

where

$$TotalPower\ cycle = (T_t * P_t) + (T_r * P_r) + (T_s * P_s)$$

- Total annual transmission energy consumption of each system

$$YearlyT_p\ DSSS = (656\mu s * 214mW) * \frac{35040\ trans}{year} * \frac{3.171E-8\ years}{s} = 1.559E-4mW\ year$$

$$YearlyT_p\ FHSS = (593\mu s * 720mW) * \frac{35040\ trans}{year} * \frac{3.171E-8\ years}{s} = 4.744E-4mW\ year$$

$$YearlyT_p\ RSVP = (1.93ms * 69mW) * \frac{35040\ trans}{year} * \frac{3.171E-8\ years}{s} = 1.480E-4mW\ year$$



Power Calculation And Comparison (8)

- Total annual receiver energy consumption of each system

$$\text{YearlyR}_{p,DSSS} / FHSS = ((736 \mu s * 1000 mW) * \frac{315360 \text{ Beacon Recptions}}{\text{year}} + (112 \mu s * 1000 mW) * \frac{35040 \text{ Acks}}{\text{year}}) * \frac{3.171E-8 \text{ years}}{s} = 7.484E-3 mW\text{year}$$

$$\text{YearlyR}_{p,RSVP} = ((990 \mu s * 129 mW) * \frac{315360 \text{ Beacon Recs}}{\text{year}} + (112 \mu s * 1000 mW) * \frac{35040 \text{ Acks}}{\text{year}}) * \frac{3.171E-8 \text{ years}}{s} = 1.277E-3 mW\text{years}$$

- Total sleep mode energy consumption of each system

$$\text{YearlyS}_{p,DSSS} = (3.153E13 \mu s - ((656 \mu s * 35040) + (160 \mu s * 315360) + (112 \mu s * 35040))) * 15 mW * \frac{3.171E-8 \text{ years}}{s} = 14.997 mW\text{years}$$

$$\text{YearlyS}_{p,FHSS} = (3.153E13 \mu s - ((593 \mu s * 35040) + (160 \mu s * 315360) + (112 \mu s * 35040))) * 15 mW * \frac{3.171E-8 \text{ years}}{s} = 14.997 mW\text{years}$$

$$\text{YearlyS}_{p,RSVP} = (3.153E13 \mu s - ((1.92ms * 35040) + (990 \mu s * 315360))) * 1mW * \frac{3.171E-8 \text{ years}}{s} = .1mW\text{years}$$



Power Calculation And Comparison (9)

- Total life span of each system

$$\text{DSSS}life = \frac{2850 mAH * 4.5v * .000114 \frac{\text{years}}{\text{hour}}}{1.559 E-4 mW\text{years} + 7.484 E-3 mW\text{years} + 14.997 mW\text{years}} = 9.74 E-2 \text{ years or } 36 \text{ days}$$

$$\text{FHSS}life = \frac{2850 mAH * 4.5v * .000114 \frac{\text{years}}{\text{hour}}}{4.744 E-4 mW\text{years} + 7.484 E-3 mW\text{years} + 14.997 mW\text{years}} = 9.74 E-2 \text{ years or } 36 \text{ days}$$

$$\text{RSVP}life = \frac{2850 mAH * 4.5v * .000114 \frac{\text{years}}{\text{hour}}}{1.48 E-4 mW\text{years} + 1.277 E-3 mW\text{years} + .1 mW\text{years}} = 14.42 \text{ years}$$

- Transmitter and receiver power consumption are the same. The significant different in power consumption comes from the different in their sleep mode power consumption. Sleep mode RSVP consumes about 150 times less power than 802.11 resulting the longer life time of the sensor of about the same factor.



Conclusion

- It is shown that modulation techniques associated with each protocol have small effect in overall power consumption
- Poor power performance of 802.11 is caused by its original idea of being a second option for setting up LAN services. Little attention was paid to the power requirements and power saving mode
- For RSVP, it cannot meet the power requirement of the system due to its communication capabilities that is not necessary