<u>RTCA Special Committee 186, Working Group 5</u>

<u>ADS-B UAT MOPS</u>

<u>Meeting #3</u>

Investigations of UAT Options for Worst-Case Link 16 Scenario

Presented by James Higbie, JHU-APL

SUMMARY

Investigations of UAT Options for Worst-Case Link 16 Scenario

RTCA SC-186 WG 5

J. Higbie

March 2001

Outline

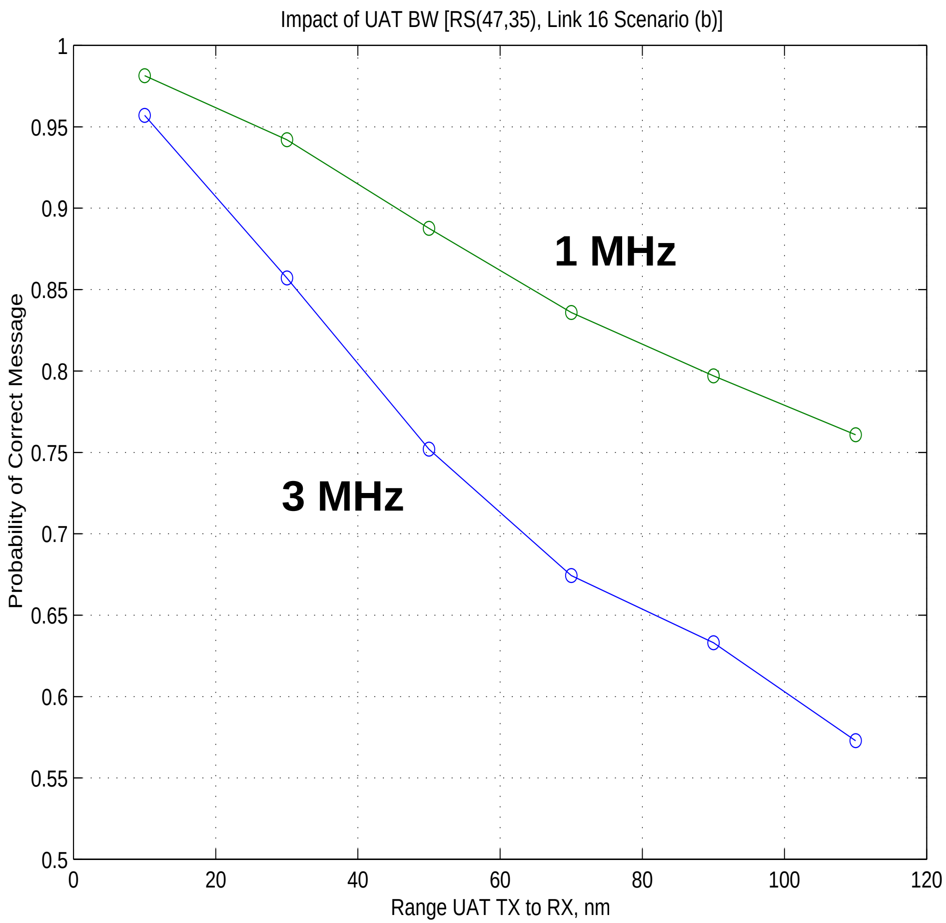
- Proposed Enhanced UAT Under Worst-Case Link 16 Scenario
- Impact of FEC length
  - No Erasure
  - With Erasure
- Impact of CRC length
  - Impact on FEC length
  - Impact on UAT Self Interference
- Conclusions

Proposed Enhanced UAT Under Worst-Case Link 16 Scenario

- Approach
  - **Interference = Link 16 Scenario (b)**
    - **From R. Weathers, WP-3-08**
      - **50% at 1000' vertical (-39 dBm)**
      - **50% at 5.9 nm (-60 dBm)**
      - **300% at 100/105/113 nm (-84.5/-85/-85.5 dBm)**
        - **Slight mod to all 3 at 100 nm in order to spread pulses in time**
  - Signal of Interest = Long ADS-B (**25 watt**)
    - RS(47,35)
      - 1 byte longer than MITRE proposal, to accommodate longer message (as directed at Meeting #2)
      - FEC length held constant
      - Note: UPSAT Proposes RS(45,33)
        - No CRC
  - (Receiver doesn't use erasures)

Proposed Enhanced UAT Under Worst-Case Link 16

Interference = Link 16 Scenario (b); RS(47,35), no erasure



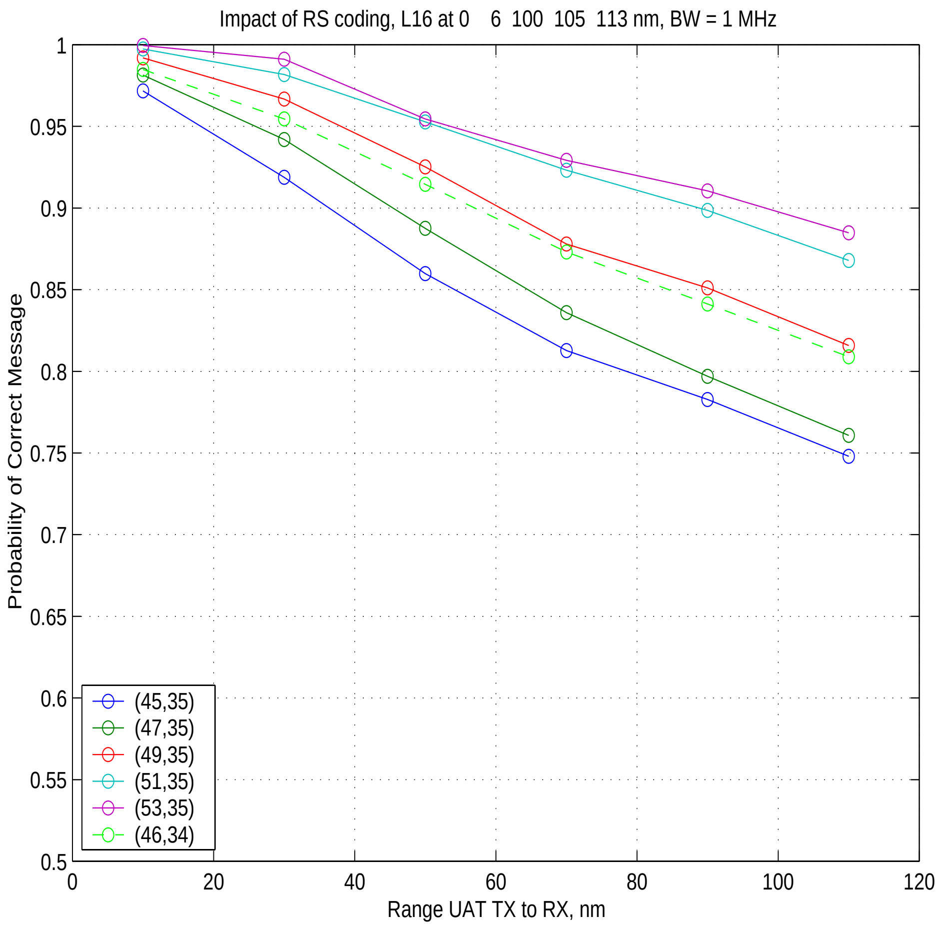
- Results
  - **Large degradation for current BW, even with enhanced coding**
    - Scenario & results are similar to those shown at Meeting #2
  - **Narrowing bandwidth to ~ 1 MHz helps a lot**
    - **But degradation is still > 10% beyond ~50 nm**

Impact of FEC Length (No Erasure)

- Approach
  - Interference = Link 16 Scenario (b)
  - Signal of Interest = Long ADS-B (25 watt)
    - **RS(n,35) for various n values**
      - **i.e. various FEC lengths = (n-35) 8-bit symbols**
  - Receiver
    - BW ~ 1 MHz
    - (Doesn't use erasures)

Impact of FEC Length, No Erasure

Interference = Link 16 Scenario (b); BW = 1 MHz



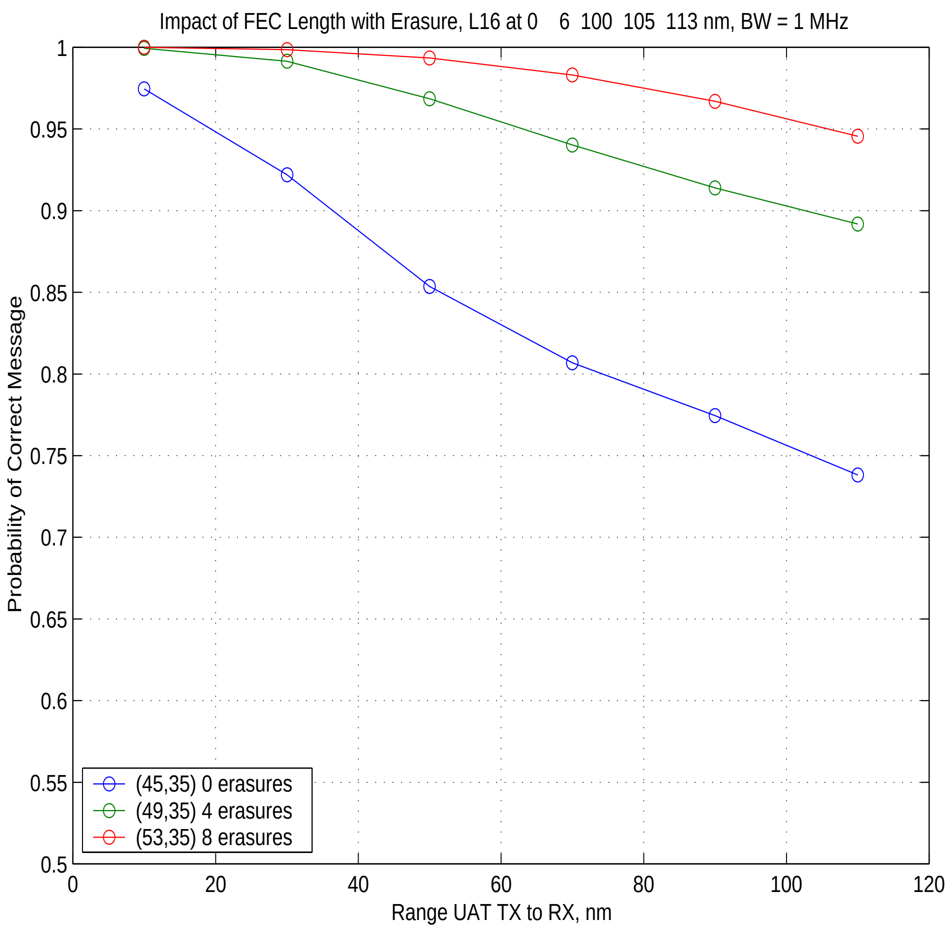
- Results
  - FEC improves performance slowly
    - **Requires n ~ 53 to keep degradation < 10% at ranges up to 100 nm**
      - **Total transmit time 26% longer than original UAT design**

Impact of FEC Length With Erasure

- Approach
  - Interference = as before Link 16 Scenario (b)
  - Signal of Interest = Long ADS-B (25 watt)
    - RS(n,35) for various n values
  - Receiver
    - BW ~ 1 MHz
    - **Max number of erasures allowed to maintain PUME constant**
      - **Number of erasures = n-45**
    - Conservative model of interference detection for erasures
      - Threshold > ~ 15 dB higher than for bit errors

Impact of FEC Length With Erasure

Interference = Link 16 Scenario (b); BW = 1 MHz



- Results
  - **FEC improves ~ twice as quickly as without erasure**
    - Requires n ~ 49 to keep degradation < 10% at ranges up to 100 nm

Impact of CRC Length

1. Impact of CRC Length on FEC Length

- Constraint: **Maintain PUME at <~ 1e-8**
  - (Value suggested by G. Ligler)
  - (MASPS say 1e-6, but should decrease as frequency of decode attempts increases)
- For Long ADS-B message, RS(n,k)
  - Assumed k = 34 + (# of CRC bytes)
  - Note: 1 byte longer payload than currently required
- Results:
  - No erasures, n = n_min
    - n_min = 48 for no CRC and k = 34
    - n_min = 45 for 1-byte CRC and k = 35
    - n_min = 44 for 2-byte CRC and k = 36
    - Found empirically by application of PUME upper bound given in MITRE's WP-2-03
  - **With erasures: n ~ n_min + nE**
    - nE = maximum # of erasures allowed to decode
    - Assumes PUME impact of each erasure is equivalent to decreasing FEC by 1 symbol at fixed n

Impact of CRC Length

1. Impact of CRC Length on FEC Length (cont'd)

- **Longer CRC can shorten total transmission**
  - **Less UAT self interference**
  - **But worse performance against Link16**
  - **Need to see which effect dominates**

- Three cases investigated:
  - RS(48 + nE, 34) for no CRC
  - RS(45 + nE, 35) for 1-byte CRC
  - RS(44 + nE, 36) for 2-byte CRC
  - These choices maintain PUME <~ 1e-8 for 34-byte payload

Impact of CRC Length

2. Impact of FEC Length on UAT Self-Interference

- Simplified Estimate of UAT Self-Interference
  - Interfering UAT ("I"):
    - Single Long ADS-B transmission (= Interferer) using RS(n,k) block lasts T_{TX} = (48 + 8*n) bits
    - Transmission start time occurs randomly within

$$T_{TOTAL} = 1 \text{ sec} – 188 \text{ msec} – T_{TX} \sim 846{,}000 \text{ bits}$$

  - UAT Signal of Interest ("S"):
    - With erasures, received message can be copied as long as central portion of RS block is received OK
      - Must receive n_{ctr} good symbols, lasting T_{ctr}:

$$n_{ctr} \sim n\_min - (n\_min - k)/2 = (n\_min + k)/2,$$

$$T_{ctr} = (8^* \, n_{ctr}) \text{ bits}$$

    - I will overlap T_{ctr} if it starts anytime within T_{BAD}:

$$T_{BAD} = T_{TX} + T_{ctr} = [48 + 8^*n + 4^*(n\_min + k)] \text{ bits}$$

Impact of CRC Length

2. Impact of FEC Length on UAT Self-Interference (cont'd)

- Simplified Estimate of UAT Self-Interference (cont'd)
  - Probability that a single I interferes with S:

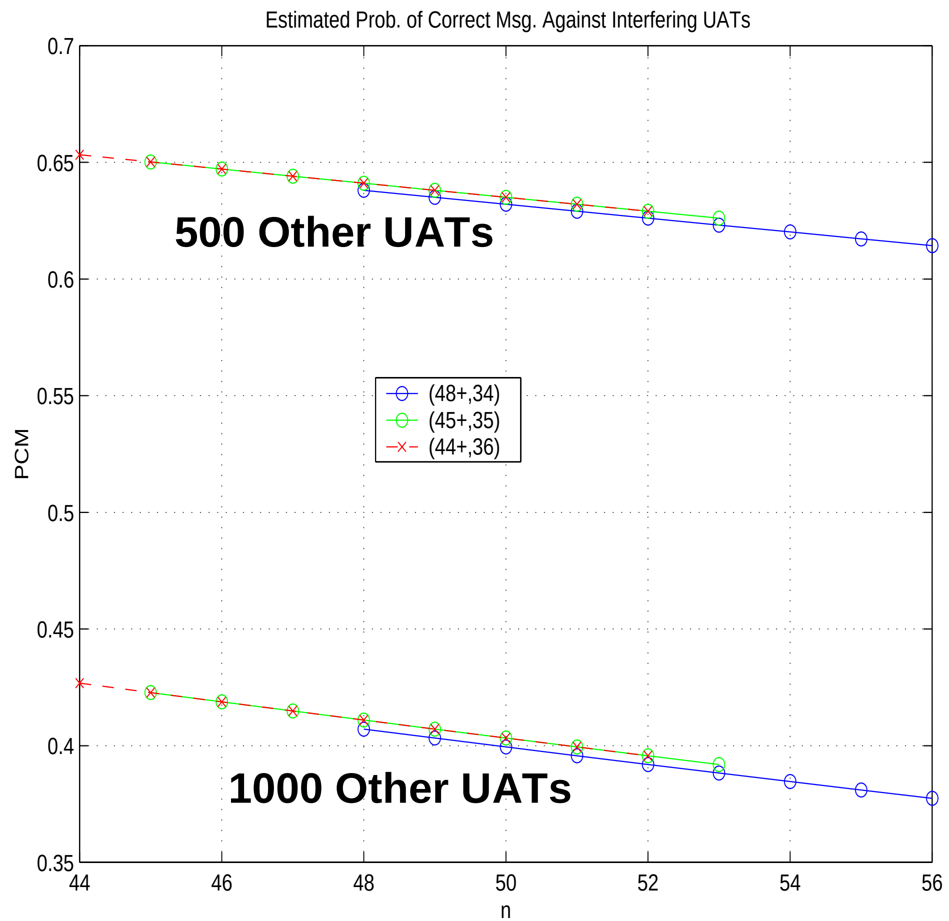
$$MER_{SINGLE} = T_{BAD} / T_{TOTAL}$$
$$= [48 + 8*n + 4*(n\_min + k)] / 846{,}000$$

  - Probability that N independent UATs interfere with S:

$$MER = 1 – (1 - MER_{SINGLE})^{N}$$

Impact of CRC Length

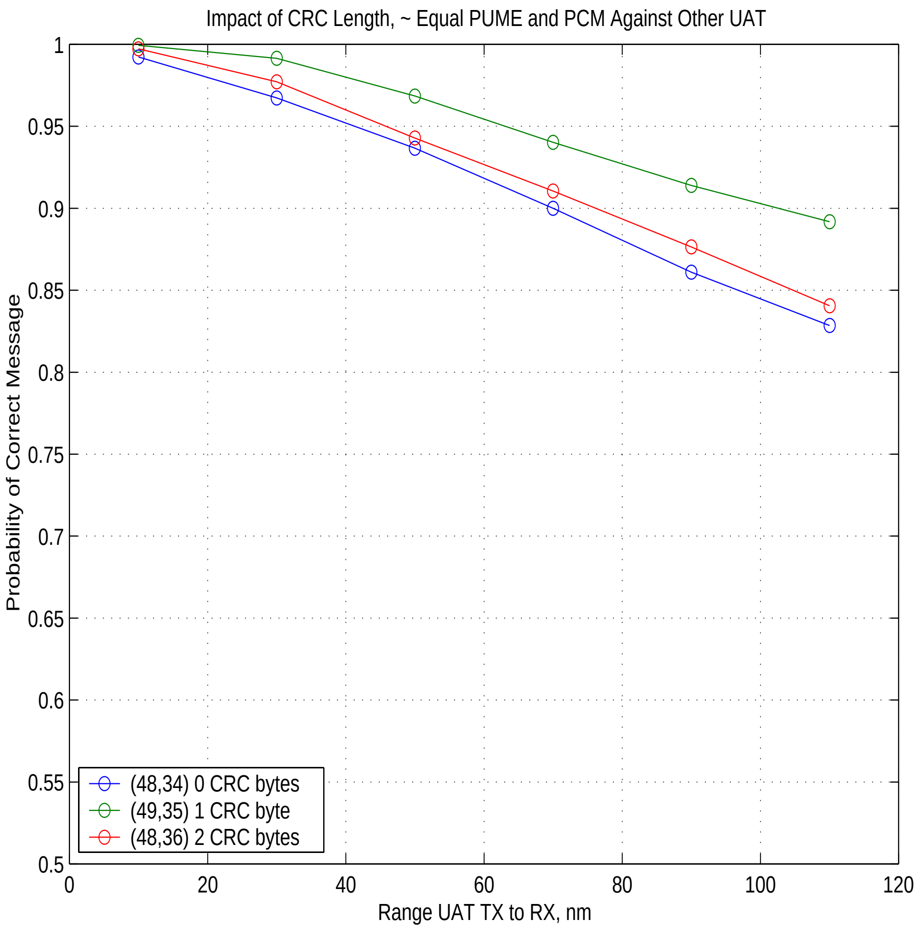
2. Impact of FEC Length on UAT Self-Interference (cont'd)



- Results
  - FEC length only weakly affects self interference
    - E.g. can be increased by 4 symbols with only ~ 5% increase in UAT self-interference
    - Assumes erasures are permitted
  - Self-interference is roughly constant for fixed (2*n + n_min + k)
    - Permits comparing different CRC lengths with same self-interference performance

Impact of CRC Length

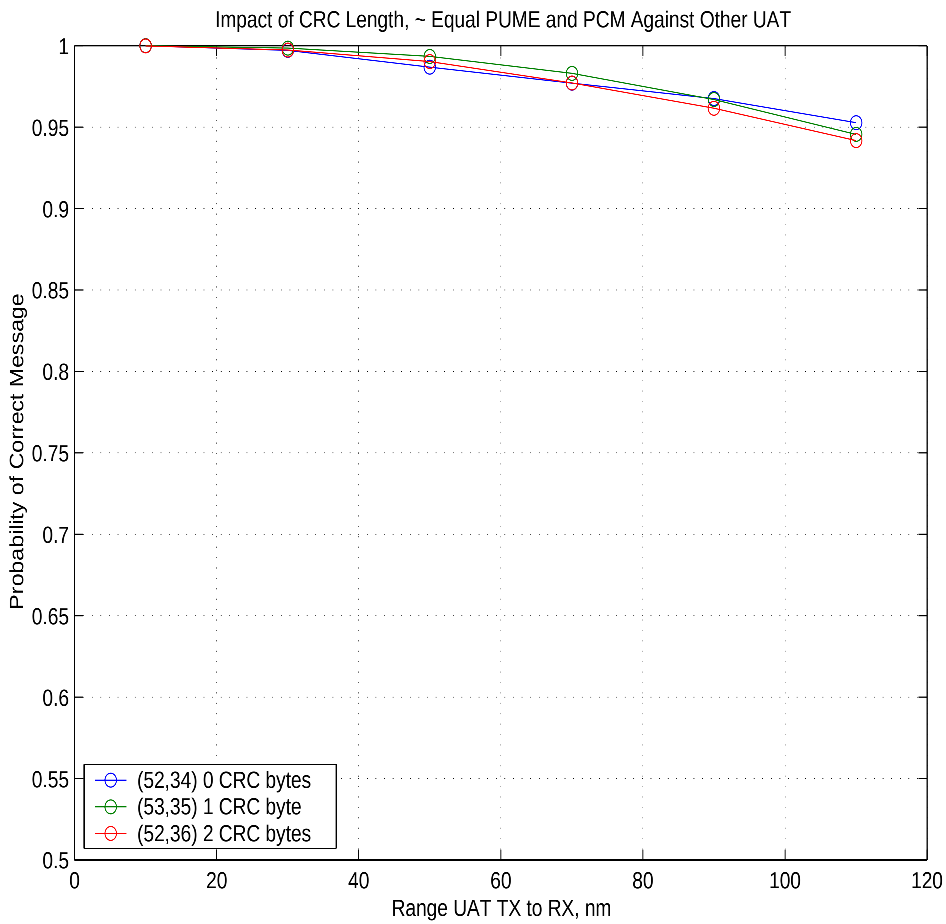
3a. Weak FEC Example



- Compare Link 16 Impact for different CRC lengths (PUME & Self-Interference held constant), erasure decoding
  - PUME <~ 1e-8
  - PCM due to Self-Interference (500 or 1000 UATs) roughly the same
    - Decreases compared to RS(47,35) by ~ 1% or 2.5%
    - Decreases compared to RS(44,36) by ~ 2.5% or 4%
- Results
  - **CRC =1 better?**
    - **Could be statistical error**

Impact of CRC Length

3b. Strong FEC Example



- Compare Link 16 Impact for different CRC lengths (PUME & Self-Interference held constant), erasure decoding
  - PUME <~ 1e-8
  - PCM due to Self-Interference (500 or 1000 UATs) roughly the same
    - Decreases compared to RS(47,35) by ~ 2.5% or 6%
    - Decreases compared to RS(44,36) by ~ 4% or 8%
- Results
  - **CRC length unimportant**
    - **Link 16 degradation about the same for all cases**

Conclusions

- Without erasure decoding, proposed RS(47,35) Long ADS-B message is significantly degraded in worst-case Link 16 scenario
  - Even with 1 MHz receive bandwidth
- With erasure decoding and 1 MHz receive bandwidth, longer codes such as RS(51,35) can operate in worst-case Link 16 scenario with much less degradation and in UAT self interference with degradation < 10%
- For 34-byte payload, RS(51,35) can achieve:
  - Link 16 degradation < 10% at UAT ranges under 100 nm
  - Degradation in self interference ~ 6% against 1000 other UATs
    - As compared to RS(44,36) (shortest message meeting PUME)
  - CRC length not very important
    - 1-byte CRC may be better than 0 or 2 (requires verification)