Agile Information Exchange in Autonomous Air Systems

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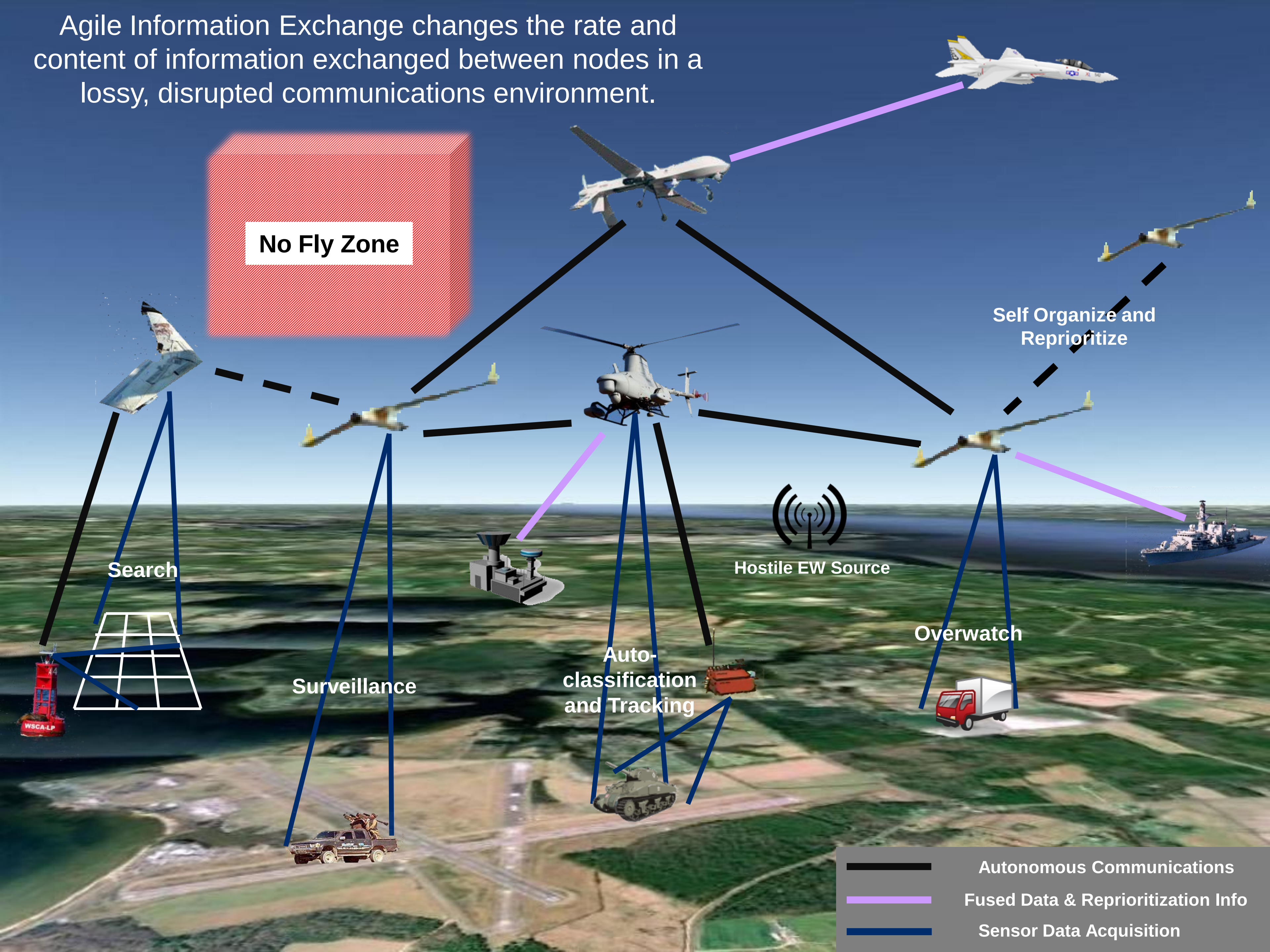

Agile Information Exchange changes the rate and content of information exchanged between nodes in a lossy, disrupted communications environment.
No Fly Zone
Self Organize and Reprioritize
Search
Hostile EW Source
Overwatch
Auto-classification and Tracking
Surveillance
WSCA-LP
Autonomous Communications
Fused Data & Reprioritization Info
Sensor Data Acquisition

Information Theory and C2

- **C2 process** $x(t)$
- **Discrete state space** $X = \{x_i\}$
- **Descriptive complexity (Hartley Information) –** $\log_2 |X|$
- **Uncertainty (Shannon entropy) –**

$$H(x(t)) = -\sum P(x_i, t) \log_2 P(x_i, t)$$

- **Information –** $I(x_i, t) = -\log_2 P(x_i, t)$
- **Observation –** $S = (\xi, t)$

Information Theory and C2

Information Decay due to Entropic Drag

- **Typically,** $H(x(t')|S) > H(x(t)|S)$ **for** $t' > t$
  - Indicates a loss of information of the observation $S = (\xi, t)$
  - We call this decay *entropic drag*
- **Sequence of observations** $S_{1:k} = \{(\xi_j, t_j)\}$
- **Define the entropic drag**

$$\Gamma(S_{1:k}, t_k, t') = \frac{H(x(t')|S_{1:k})}{t' - t_k}$$

Information Theory and Tracking

- **Assume a single target in discrete time and space**
- **State transitions with known probability**
  - $x_j \to x_i$ with known probability $P_{x_j}(x_i)$
- **Given** $P(x_i, k)$ **have** $P(x_i, k+1) = \sum_{x_j \in X} P(x_j, k) P_{x_j}(x_i)$
- **Can repeatedly apply this relationship to calculate distribution over time**
  - This motional model induces the entropic drag!

Sensor Resolution and Entropy

- **At last year's ICCRTS we discussed how the motion model of a target affects entropic drag**
- **Here, motion model is fixed**
  - Instead, the resolution of the sensor is varied
  - The underlying state representation is kept the same

Sensor Resolution and Entropy

- **Suppose state X is split into $N \times N$ grid**
  - Descriptive complexity is $2\log_2 N$
  - Tracked object moves (or stays put) every T_s seconds
- **Have a finite number of sensing options i**
  - Each represent a quantization factor q_i on the underlying state
- **The number of bits required to encode an observation using quantization factor q_i is**

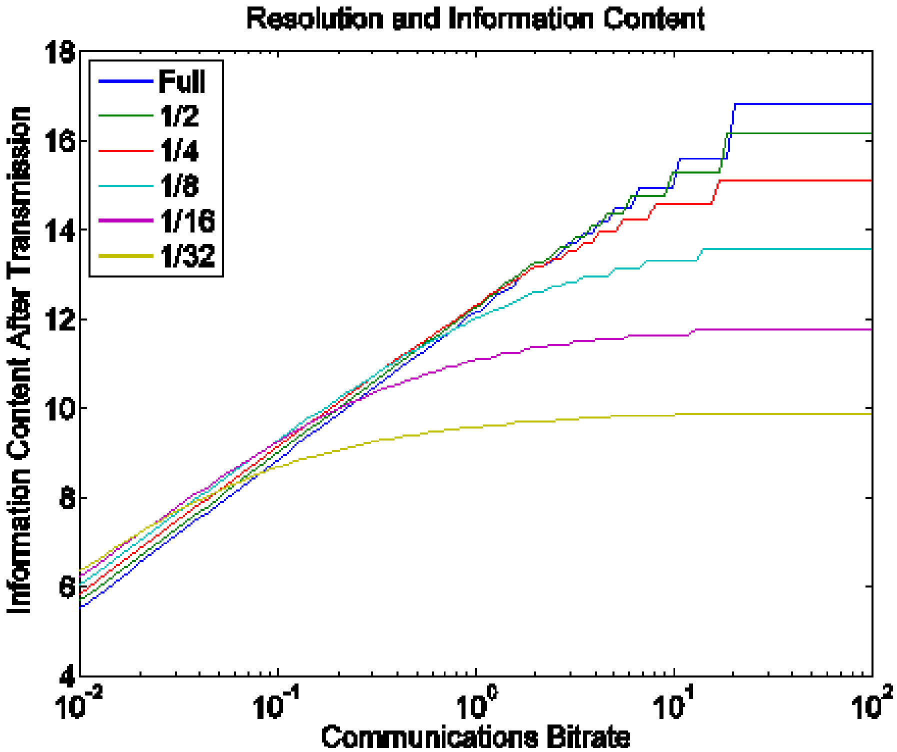
$$\log_2\left(\frac{N}{q_i}\frac{N}{q_i}\right) = 2\left(\log_2 N - 2\log_2 q_i\right)$$

Sensor Resolution and Entropy

- **Just because observations have been coarsened does not mean state model should change**
- **Observation using sensor i contains the same amount of information as knowing the target is in a q_i by q_i area**
  - So the initial observation is less informative
- **Information content of observations degrade due to target motion while message is being transmitted**
- **For a given bitrate r the number of target steps can be computed by** $M = \left\lceil \frac{2(\log_2 N - 2\log_2 q_i)/r}{T_s} \right\rceil$

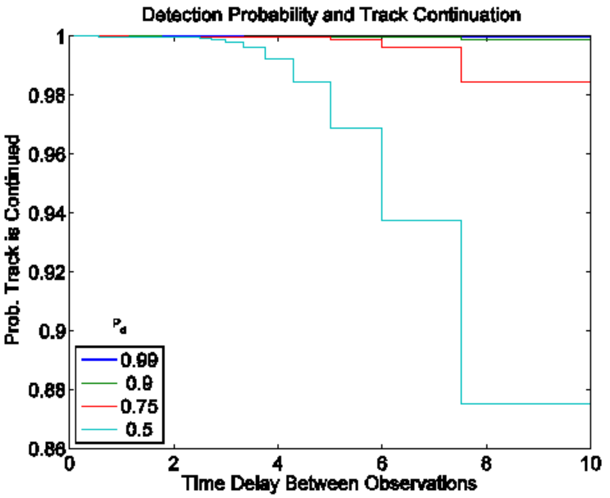
Resolution and Timeliness Tradeoffs

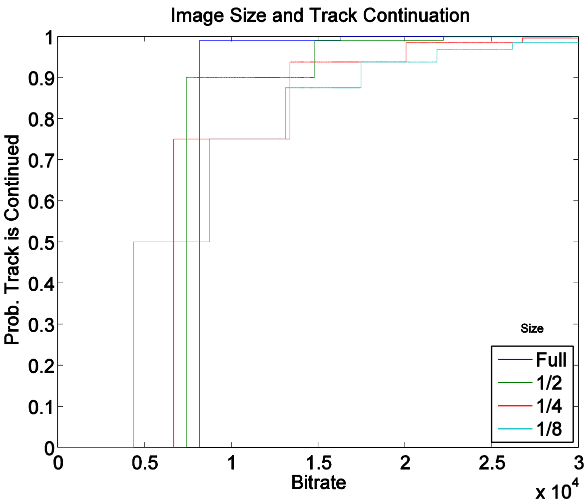
- **These computations indicate that the relative performance of the different coarsening factors varies with the communications capabilities**



- **Information content is not the only metric to be considered in a tracking problem**
- **Probability of target detection p_d should increase with increased resolution and vice-versa**
- **Probability of track continuation p_c depends on**
  - Probability of detection
  - Time between consecutive observations
- **We base p_c on receiving detection in a window of L sec**
- $p_c = 1 - (1 - p_d)^{\lfloor L/T \rfloor}$, **where** $T = B\left(\frac{N^2}{{q_i}^2}\right)/r$

- **These equations can be used to produce notional curves illustrating different ranges of dominance**
- **Requires knowing the p_d for a given image size, and an acceptable value for L**
- **Also need to consider image quality, as typical images use many less bits than their raw formats would suggest**

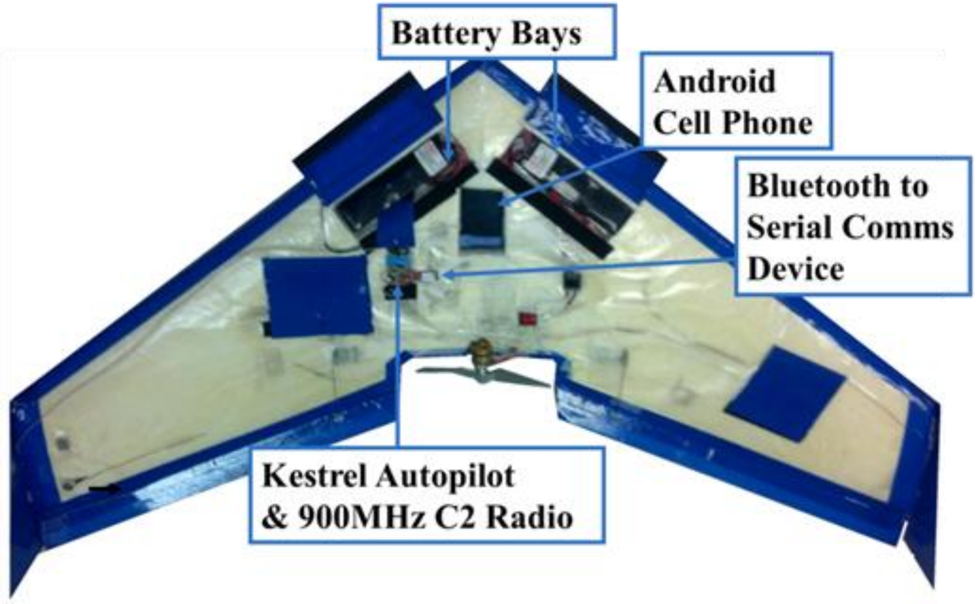




Experimentation

Test Platform

- **Modified Procerus Unicorn**
  - Electronically Powered
  - 72” wingspan
- **Kestrel autopilot**
  - 900MHz connection to ground station
- **Samsung Galaxy SII**
  - Android 4.1.2
  - ATT Network

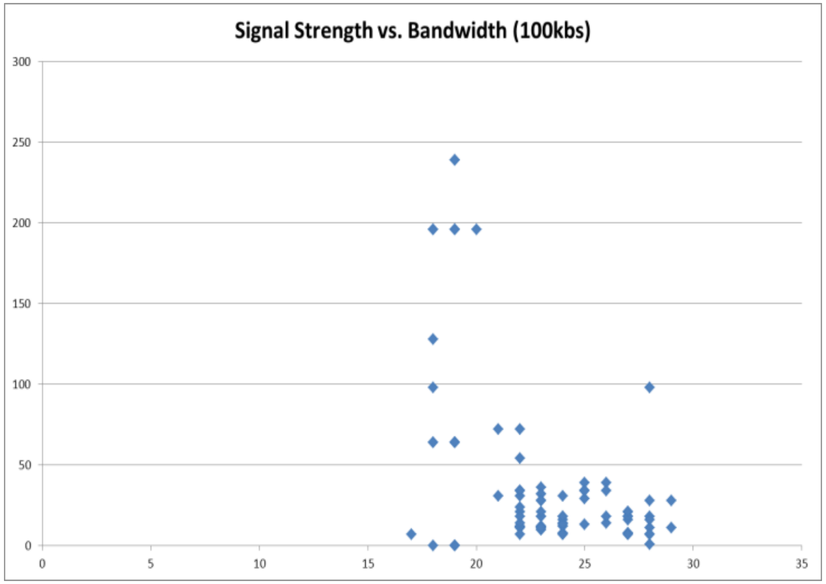


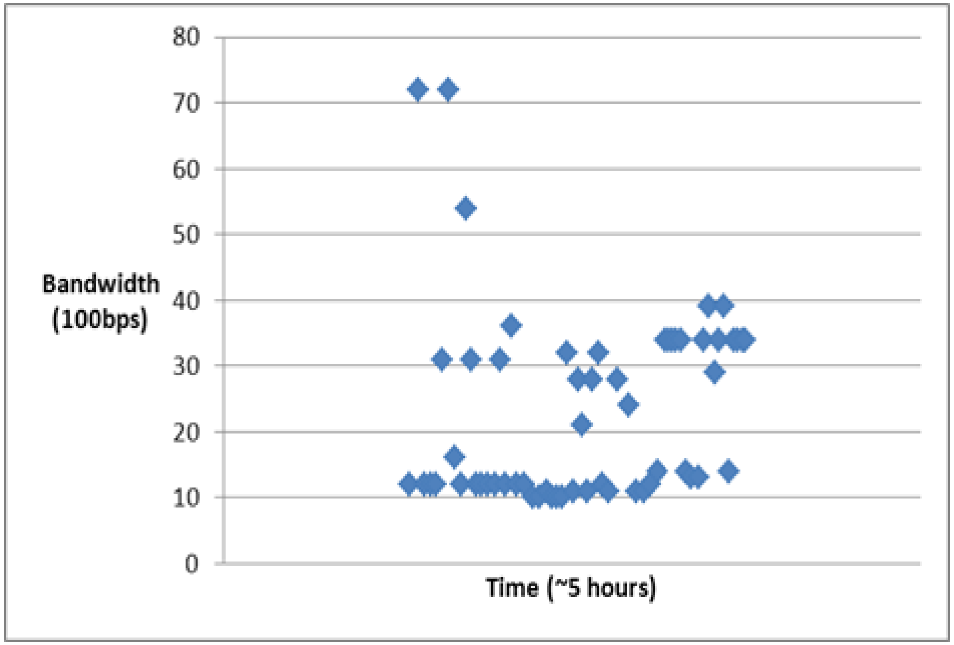
Agile Information Exchange Algorithm

- **UAV sends messages continuously**
  - Camera faster than network, so it waits until message is finished sending
  - Otherwise messages can come out of order
  - Frame rate is equal to image size/bit rate
- **Algorithm estimates current bandwidth**
  - Moving average over previous messages
- **Algorithm estimates next message size**
  - Based on average of sizes for a given quality
- **Algorithm varies image quality to maintain delay**
  - Uses highest image quality possible with expected delay less than desired
  - Uses estimates of current bandwidth and message size

Communications Baseline

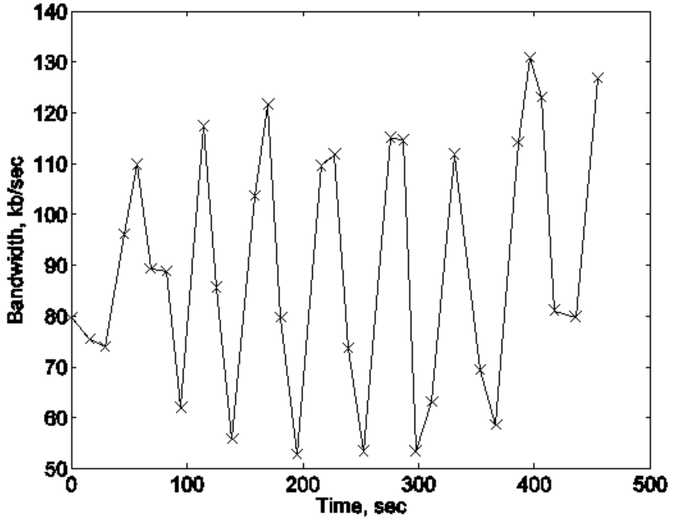
- **For the agile information control algorithm to be of value:**
  1. Network QoS must vary over the course of an engagement
  2. Rate at which it varies must be significantly less than the time required to send an image





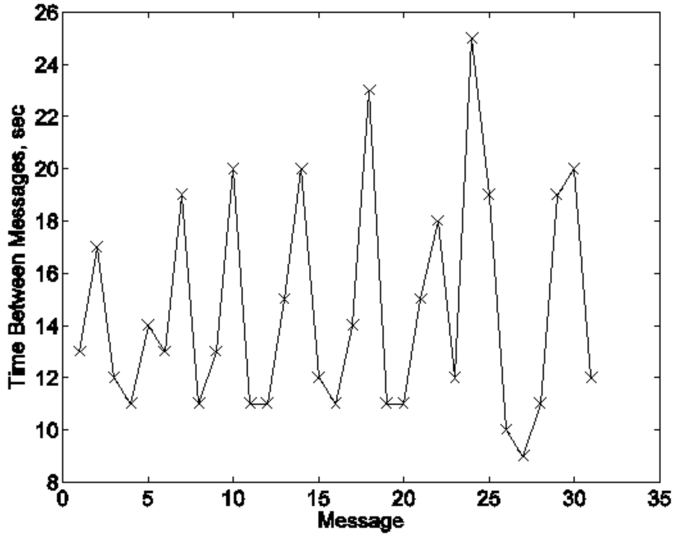
Flight Experiment Results

- Bandwidth per message was not as smooth as in lab
- In fact nearly perfectly periodic
- Loitering of aircraft was periodic
- Suspect that attenuation or directionality of antenna is the culprit, not distance to the cell tower



Flight Experiment Results

- **Since the bandwidth varied faster than the message interval, estimated delays between messages inaccurate**
- **Also, message sizes were substantially larger than baseline**
  - More information content in the air than in the lab!



Conclusion

- The periodicity in bandwidth is highly predictable and could in principle be incorporated into bandwidth estimation
- Image size as a factor of quality should be revised online

Questions?

- This research was performed under the APL Student Program to Inspire, Relate and Enrich (ASPIRE) program