Notes on the Stochastic Unified Multiple Access (SHUMA) Protocol

John Custy/SSC-SD
john.custy@navy.mil
Overview/Summary

• Background on Link-16
• SHUMA: Motivation & Characteristics
• Performance Measures
  – Time Slot Usage
  – Average Receive Interval
  – Channel Access Latency
  – Behavior as Number of Users Increases
• Summary/Conclusions

SHUMA: Adaptation without Overhead
Background on Link-16 (1/3)

- Provides *Situational Awareness*: Position & Status of Other Network Participants, etc...
- TDMA Channel: Users are Allocated Time Slots
- Link-16 is a Line-of-Sight System
- PPLI: Precise Participant Location & Identification

*PPLI Messages: Position and Status of Friendlies*
Background on Link-16 (2/3)

- Link-16 Channel: 1536 Time Slots per 12 Second Frame
- Conventional Channel Access Protocols
  - Dedicated Access: Exclusive Use of Specific Time Slots
  - Contention Access: One Transmission per Access Interval

DA & CA: Transmission Rates are Fixed Before Deployment
Simultaneous Xmissions: Receivers are “Captured” by the Transmitter that is Physically Closest

Capture Effect Mitigates, but Does Not Eliminate, Consequences of Simultaneous Xmissions
Problem Statement & (iffy) Answer

• Q. How Should Link-16 Time Slots be Allocated in a Dynamic Environment?
• How About Using the Channel Itself to Allocate Slots?
  – But a Protocol is Needed for the Protocol…
  – Robust to Channel Errors? Connectivity Not Guaranteed…
  – Not Scalable: Two Distinct Types of Info on Channel…
SHUMA (1/2)

- Each Terminal Uses only *Local* Information
- A Terminals Probability of Transmission Depends on
  - The number of users
  - Past transmission history
    \[ p_i(t) = \frac{1}{N_i(t)} + \left(1 - \frac{1}{N_i(t)}\right) \left(1 - \left(1 - \frac{1}{N_i(t)}\right)^{B_i(t)}\right) \]
    \[ (1) \]
- This Probability of Transmission Maximizes the Probability of a Single Transmission in a Time Slot
- Proper Choice of Parameters Allows SHUMA to Mimic Behavior of DA and CA

*Situational Awareness Guides Adaptation*
SHUMA Characteristics (2/2)

- SHUMA is
  - Scalable: Entire Channel is Dedicated to User Data, Regardless of the Number of Users
  - Robust: Degrades Slowly when Counts are Incorrect
Time Slot Usage: Contention Access

CA Performance Depends on the Number of Users
Time Slot Usage: SHUMA

Time Slot Usage for SHUMA with $S=0$

Analysis for $N=2$ (Blue) to $N=64$ (Red) Users

Performance Practically Independent of Number of Users
Size of Access Interval is Fixed by Terminal Load, so CA ARI Curve Does Not Change During Deployment
Under SHUMA, Users “Think Globally and Act Locally”
Channel Access Latency

Probability of Interval Between Transmission, CA & SHUMA
CA with 16 Slots per Access Interval in Black
SHUMA with $N=16$, $\beta$ from 0 (Red) to 6 (Blue)

Intervals Between Transmissions Decay Geometrically...
Behavior for Large $N$ (1/2)

- Q. What happens to throughput as the number of users increases?
- A. Time Slot Usage changes from Binomial to Poisson Distribution…

This Establishes a Lower Bound on Channel Throughput
Behavior for Large $N$ (2/2)

$$\Pr_{\text{SHUMA}}(k, N) = \binom{N}{k} p^k (1 - p)^{N-k}, \text{ with } p = 1 - (1 - 1/N)^{1+\beta}$$

(1)

Though this expression becomes a bit complicated when the substitution for $p$ is explicitly carried out, it simplifies considerably when $N$ is large.

Equation (4) represents the probability that $k$ participants will transmit during a particular time slot. When we replace every occurrence of $p$ with the general SHUMA probability of transmission we get a rather complex expression...

$$\ln[3] := \frac{N!}{(N-k)! k!} p^k (1 - p)^{N-k} / . p = 1 - (1 - 1/N)^{1+\beta} \ // \text{FullSimplify}$$

$$\text{Out}[3] := \frac{\left(1 - \left(\frac{-1+N}{N}\right)^{1+\beta}\right)^k \left(\left(\frac{-1+N}{N}\right)^{1+\beta}\right)^{N-k} N!}{(N-k)! k!}$$

...but it becomes much simpler when $N$ is large. The term "/ . " above means "replace all" and, as before, the symbol "$\%$" represents the immediately preceding expression.

$$\ln[4] := \text{Limit}[% , N \to \infty]$$

$$\text{Out}[4] := \frac{e^{-1-\beta} (1 + \beta)^k}{k!}$$
Summary/Conclusions

- Adaptive without the burden of overhead
- A Natural Complement to Existing Protocols
- Applications Beyond Link-16
  - Sensor Fields?
  - Robotics?

*Principled Design, Simple Analysis, Robust Performance*
“JTIDS units automatically transmit and receive data at preassigned times on preassigned nets based on instructions given to their terminals when they are initialized. These preassignments are determined in advance of operations to support the expected information exchange requirements of the force.” - Understanding Link-16