

Advanced Communications for Air Traffic Management **AC/ATM**

NASA Satellite Networks and Architectures Branch

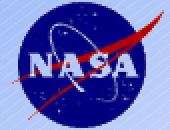
Glenn Research Center

Dual Purpose Simulation: New Data Link Test and Performance Limit Testing of Currently Deployed Data Link

Presentation

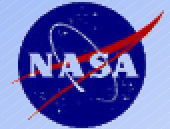
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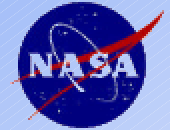
Aim

- To test a variant of the CSMA Access protocol, PCSMA, in a fairly realistic/robust communications environment in terms of traffic volume and frequency.
- To compare with the known behavior of VDL-2 to see whether PCSMA is a significant improvement.
- To obtain an upper bound for performance of VDL-2 with given traffic.
- To underscore the importance of an efficient access scheme and provide a tool for determining optimum access scheme-performance.
- To establish good baselines or foundations, not only for PCSMA and CSMA, but also for VDL-3 (TDMA) simulations.



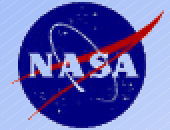
Background

- Lack of surveillance and communications coverage => slow and costly routes.
- Great expected user demand for scheduled air service intensifies problem (3X).
- Solution: Free-flight = operating system giving pilots freedom to select own path and speed in real-time.
- One application is viewed as essential to free-flight (ATC):
 - Controller Pilot Data Link Communications (CPDLC).
- Bandwidth limitations: Narrowband channels and spectrum/freq. shortage
- For probably next 20 years, Very High Frequency Data Link Mode 2 (VDL-2) will be “bread and butter” link.
- VDL-2 uses CSMA, more discussion later.



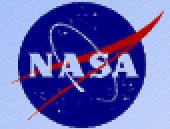
Overview

- All aircraft assumed to use CPDLC over “VDL-2” (PC-SMA).
- 1,235 aircraft, 111 ATC ground stations, 32 airports, 32 ATC towers, 24 hours simulated time.
- Realistic communication modeled solely for all incoming and outgoing air traffic originating and terminating at an airport in three cities: Cleveland, Detroit, and Cincinnati.
- 29 (= 32 – 3) airports across the country are sources or destinations of that air traffic.
- Ignores weather and terrain, assumes perfectly spherical earth.
- Since “the MAC layer is especially important in LANs,” simulation solely captures CSMA aspect of VDL-2’s behavior as well as its radio frequency assignment.

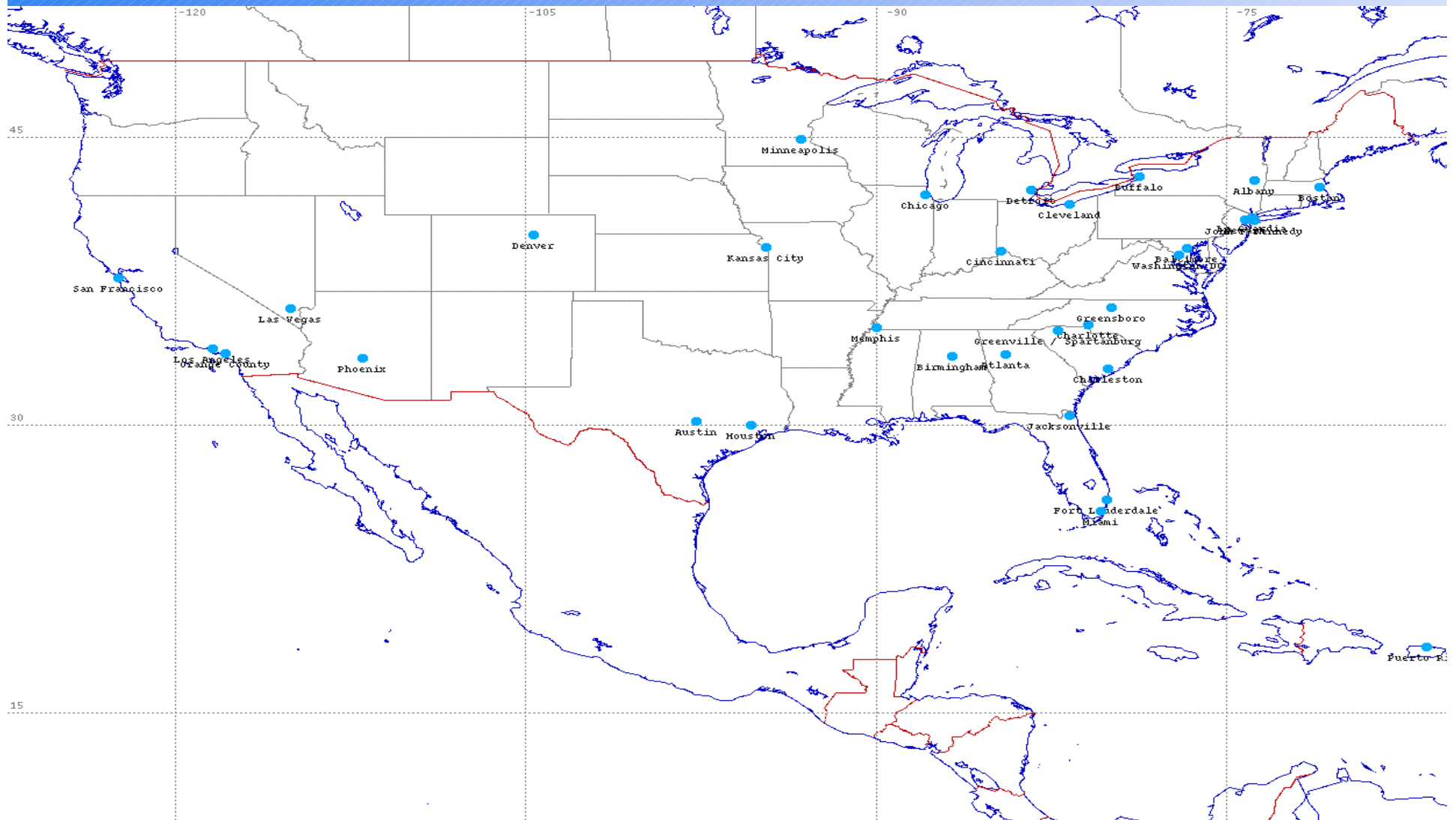


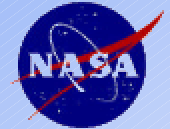
Overview, cont'd.

- CPDLC modeled as unreliable.
- Measures latency and packet loss.
- Simulated CPDLC messages size: 5000 bit mean, normal distribution;
- 6, 3, and 1.5 minute mean interarrival time/simulation, exponential distribution.
- Actual standard CPDLC packet size = 8312 bits.
- All CPDLC transceivers at 136 MHz. (VHF)

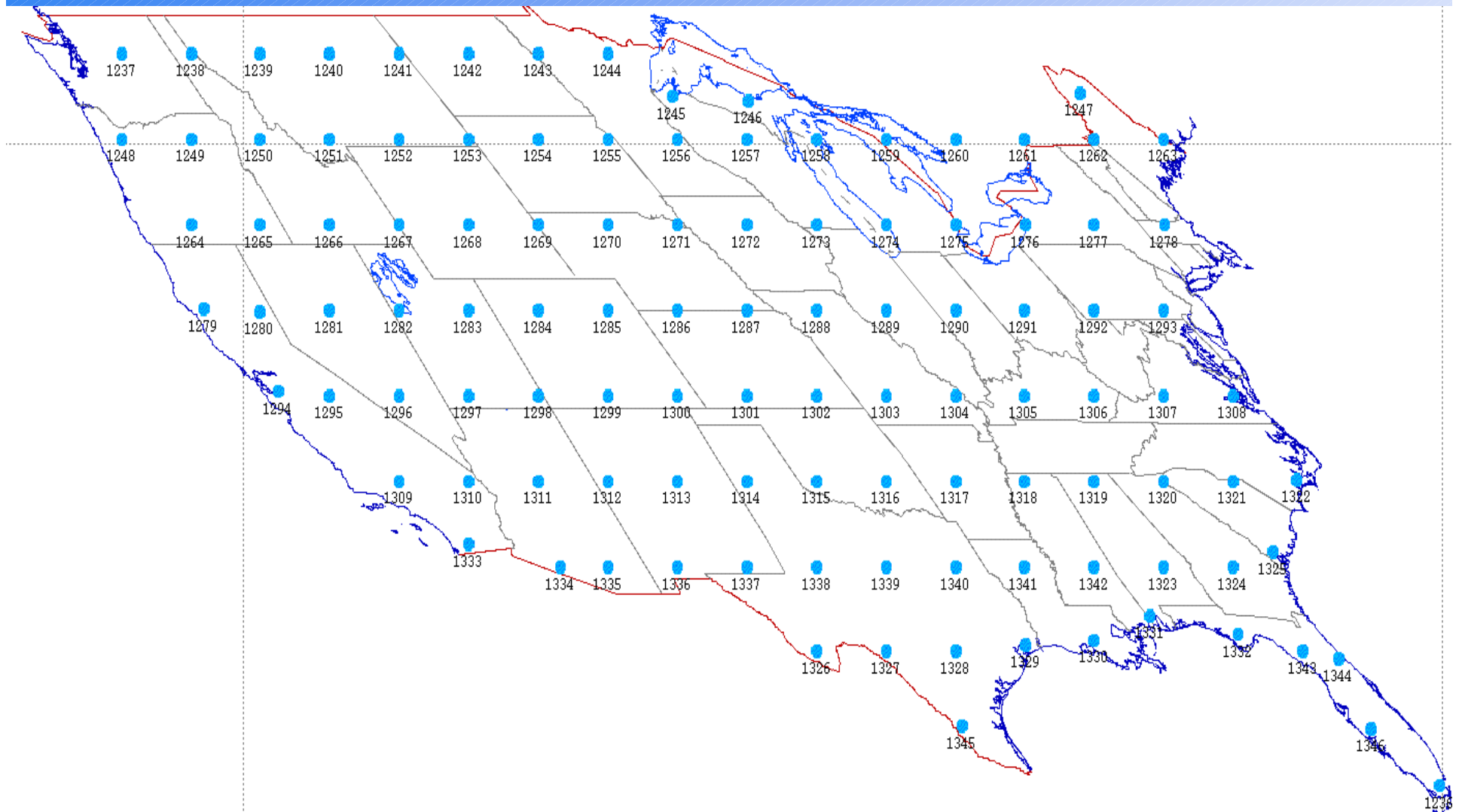


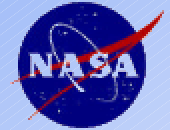
32 Actual Airports





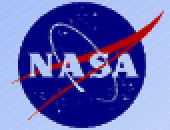
111 Uniformly Distributed Ground Stations





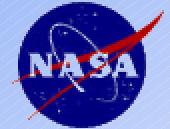
CSMA Discussion

- Listen first; if channel silent, then begin to speak.
- One frequency used, which conserves spectrum.
- Only one station “talks” at a time.
- If two stations within LOS talk at the same time, a collision occurs; once sensed, the stations back-off a random time before attempting to talk again.
- Contention (collisions) make CSMA very inefficient.
- Operators of datalink type services need not wait to speak, pilot types a request and the machinery determines when to transmit.



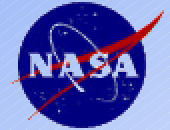
Prioritized (collision-free) CSMA

- Establish a second “common” channel which carries tiny information packets
- Information packets convey station intent to talk data, such as check-in time or queue length.
- Transmission priority on first come, first serve basis.
- When medium busy, each transmitter receives waiting ticket, when free, each takes its turn sequentially.
- Through use of tiny information (cnctrans) packets on a second frequency, each node knows who transmits next.
- When channel is free, no contention, no collisions.



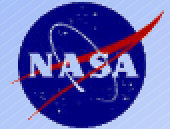
How Prioritized CSMA Works

- Each node broadcasts a zero-length information “cnctrans” packet containing a unique “srcid” code, timestamp, and the queue length of that node.
- When a node receives a cnctrans packet, it updates an array including its neighbors’ transmission priority.
- If a cnctrans packet from a node has not been received in time, it’s assumed unreachable.
- When a node seizes channel, all nodes wait until it’s finished, next node begins orderly transmission.

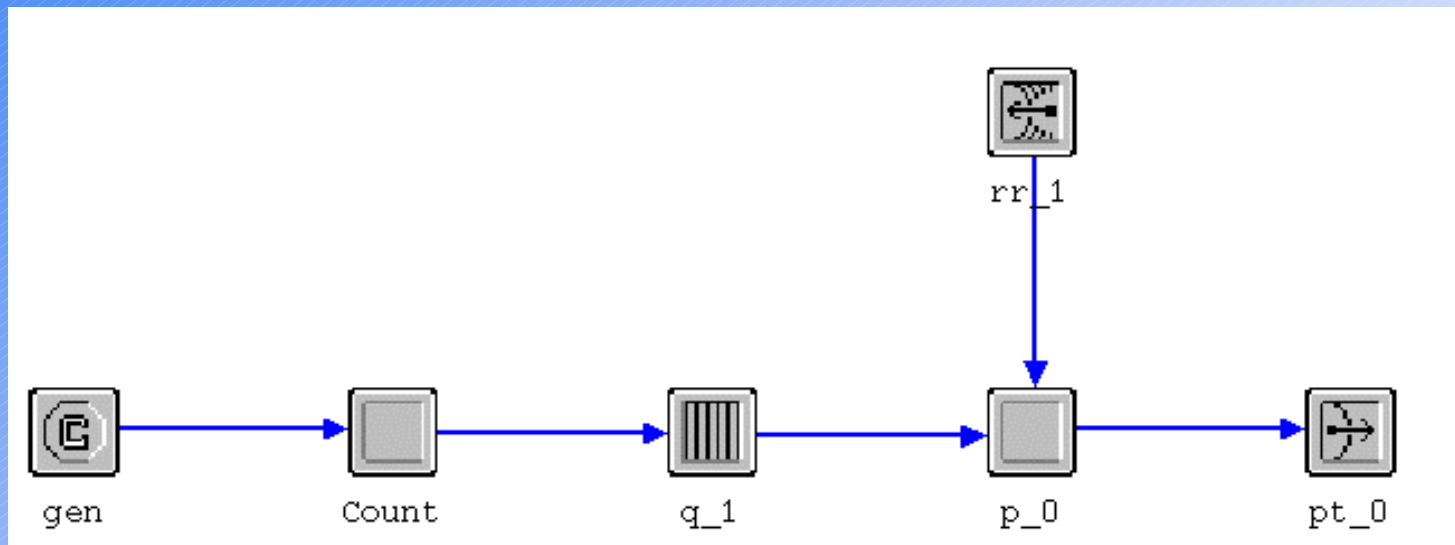


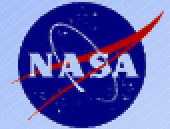
How Prioritized CSMA Works, cont'd.

- Cnctrans packets don't collide since they're small and each node is assigned a unique phase lag with which to broadcast them.
- Just as truckers on opposite sides of the country use the same CB radio frequencies to talk without interference, so different LOS groups can communicate on same frequencies simultaneously without interference.

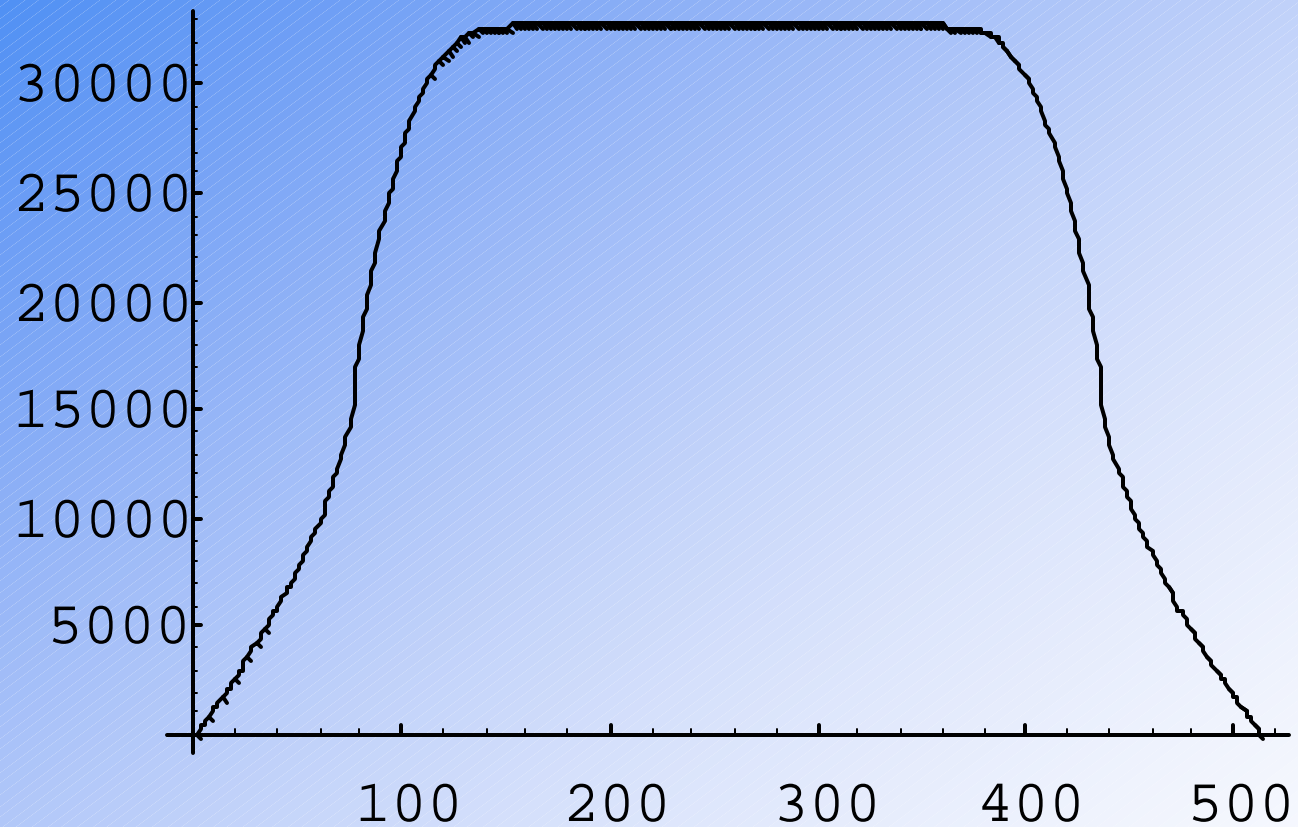


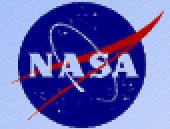
CPDLC Node Architecture



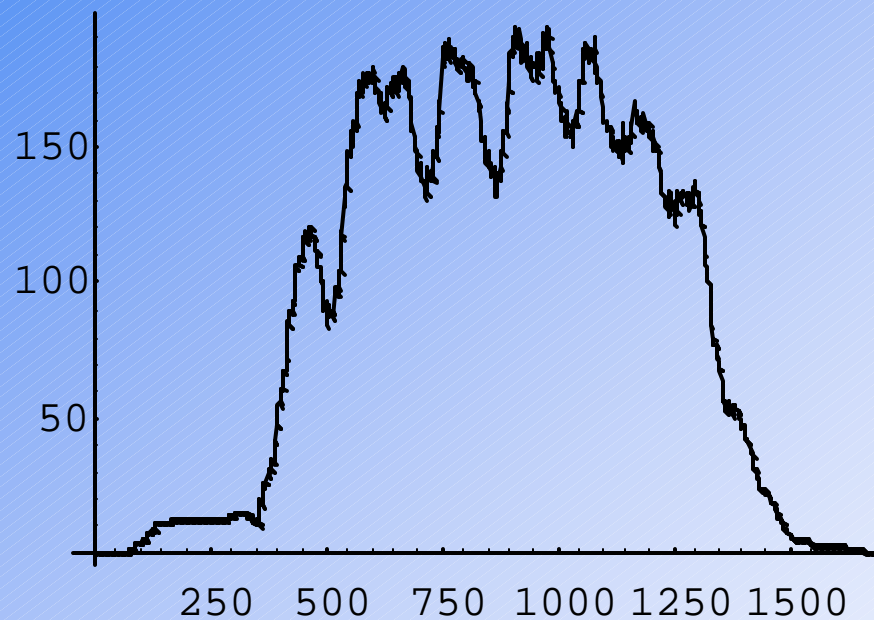


Sample Aircraft Trajectory (ft. vs. sec/10.)

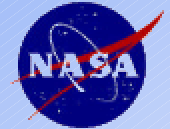




Planes Aloft vs. Time of Day (min.)



- The average number of planes flying is 90.8.
- Peak traffic is at (60 s/min) (910 min.) = 54,600s, or 3:10 p.m.
- From actual airport data.



Simulation Runs

- There were six simulation runs (I –VI),
- I & IV : 6 minute mean CPDLC interarrival time.
- II & V : 3 minute mean CPDLC interarrival time.
- III& VI: 1.5 minute mean CPDLC interarrival time.
- “X” = No Access Scheme. All transceivers set at 31.5 Kbps.
- “D” = Mean ETE delay of CPDLC packets.

I: X, D = 0.3182 s. (T,R) = (38412,34012)

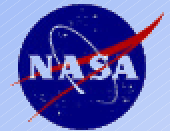
II: X, D = 0.3184 s. (T,R) = (77760, 61807)

III: X, D = 0.3188 s. (T,R) = (156512,104252)

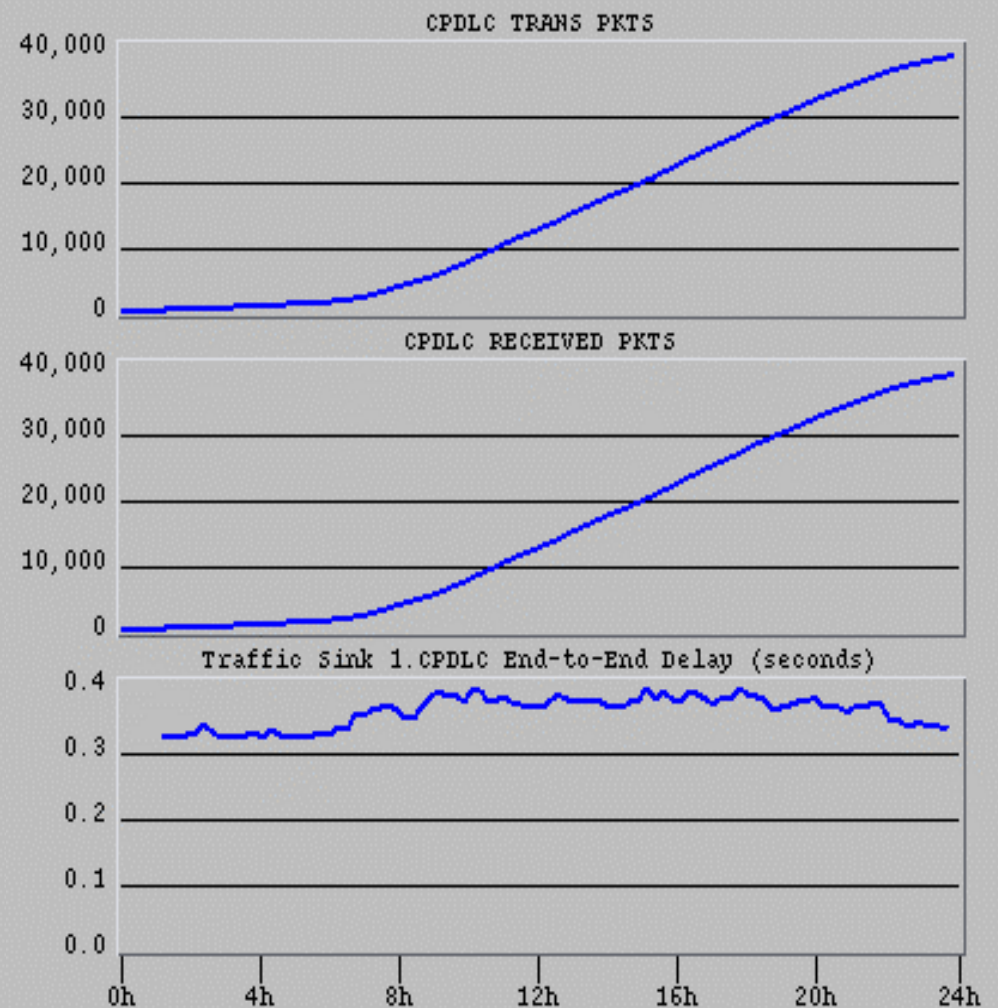
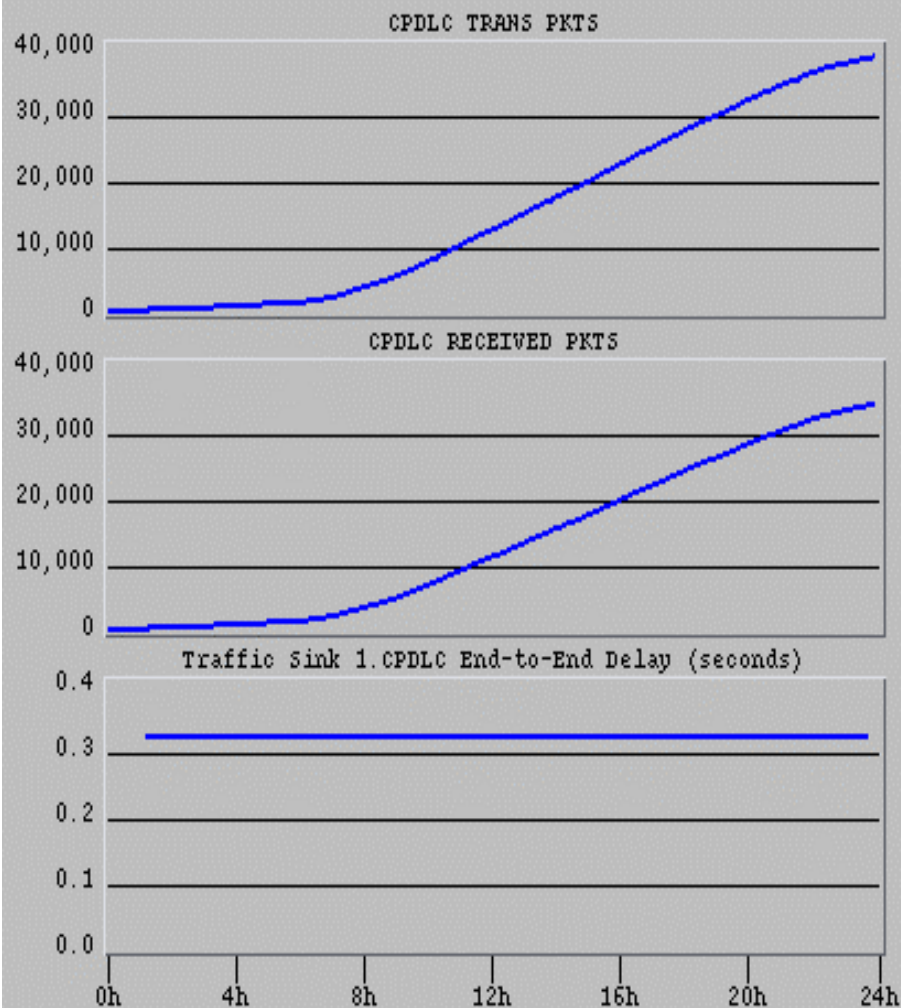
IV: PCSMA, D = 0.3582 s. (T,R) = (38529,38529)

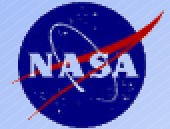
V: PCSMA, D = 0.4039 s. (T,R) = (77140,77140)

VI: PCSMA, D = 0.5772 s. (T,R) = (154304,154304)

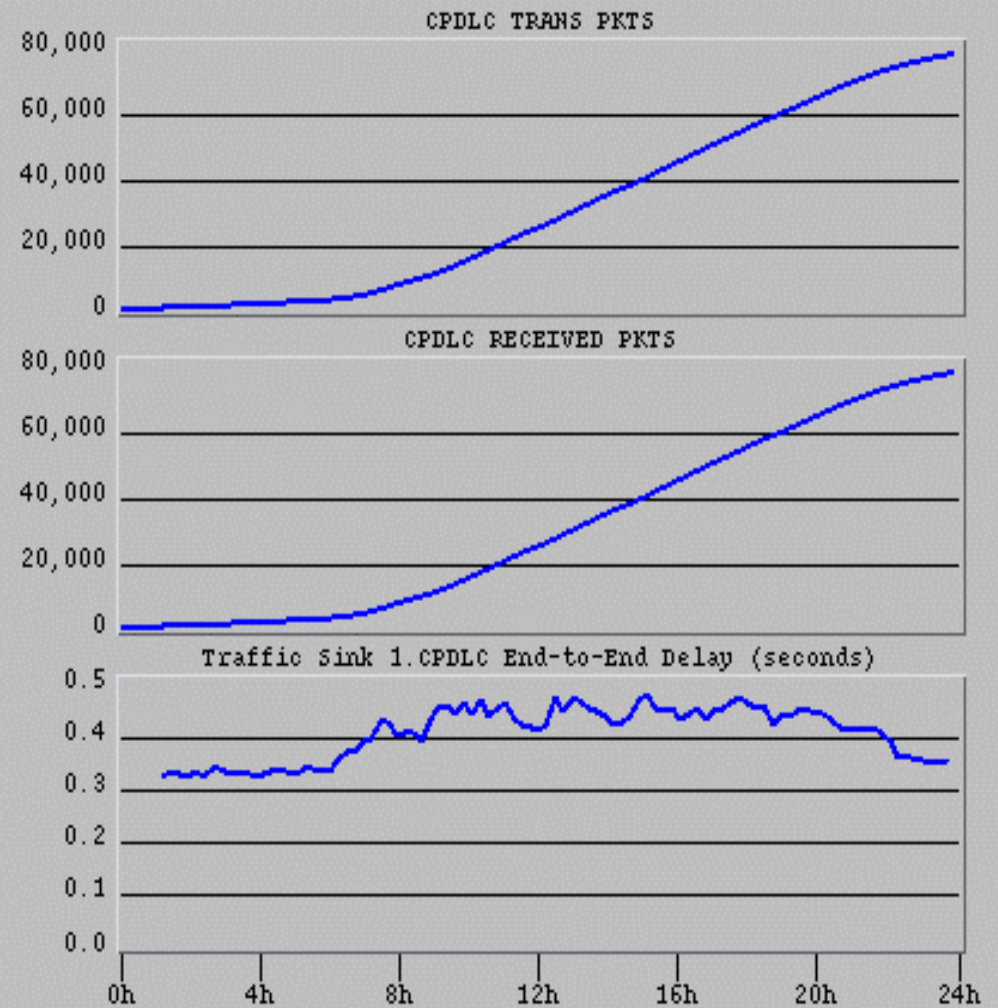
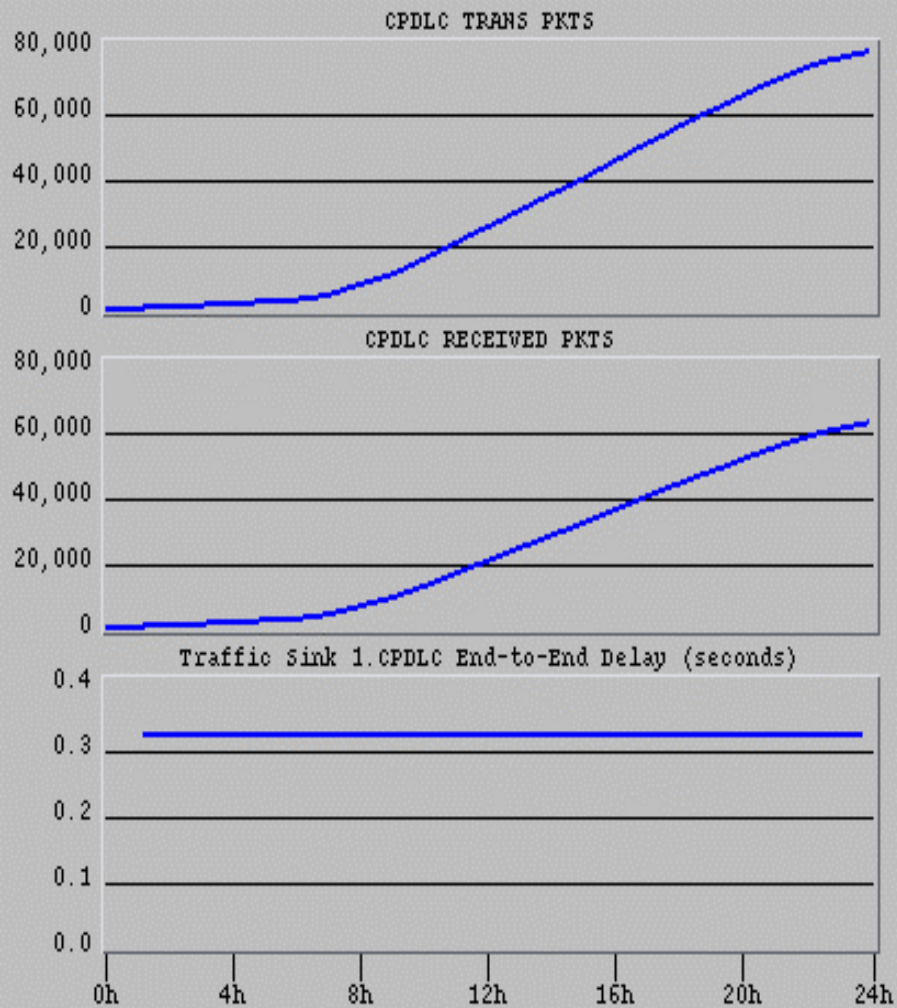


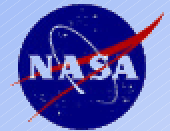
ETE Delay (I & IV, $D = 0.3182$ s, $D = 0.3582$ s)



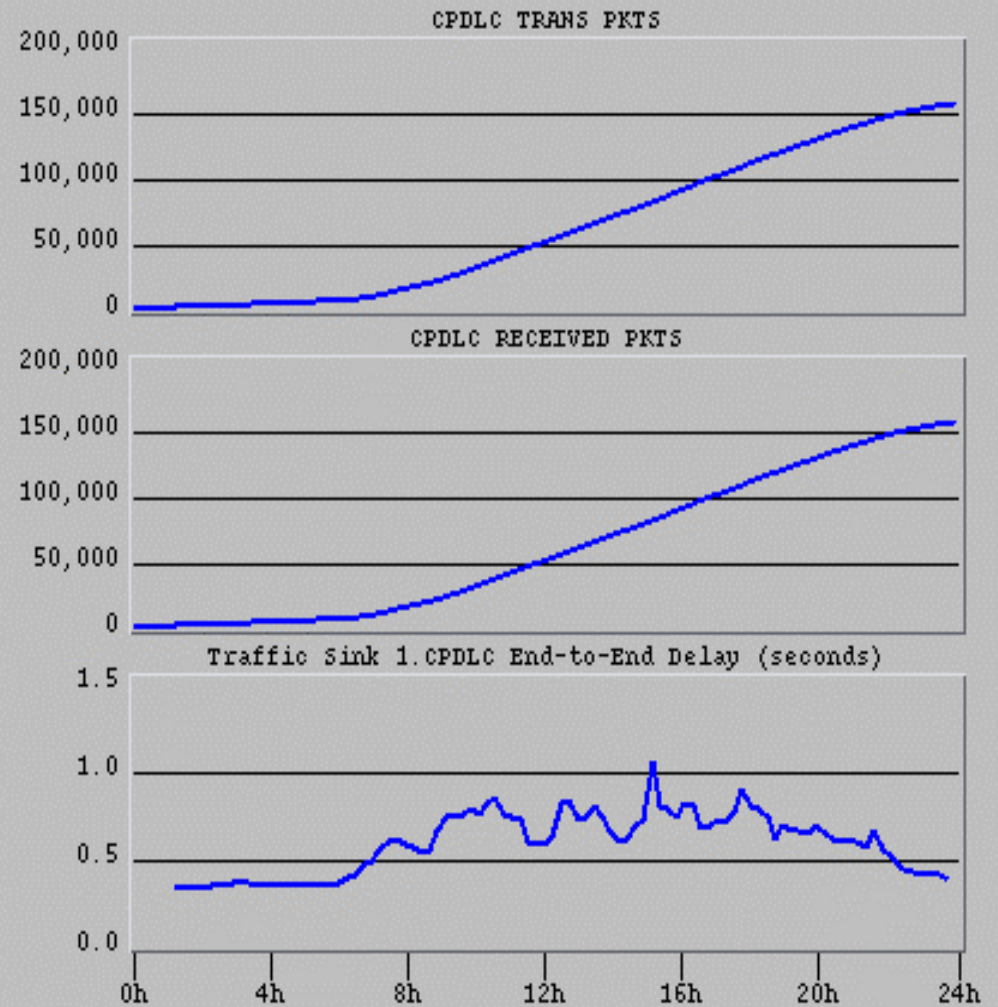
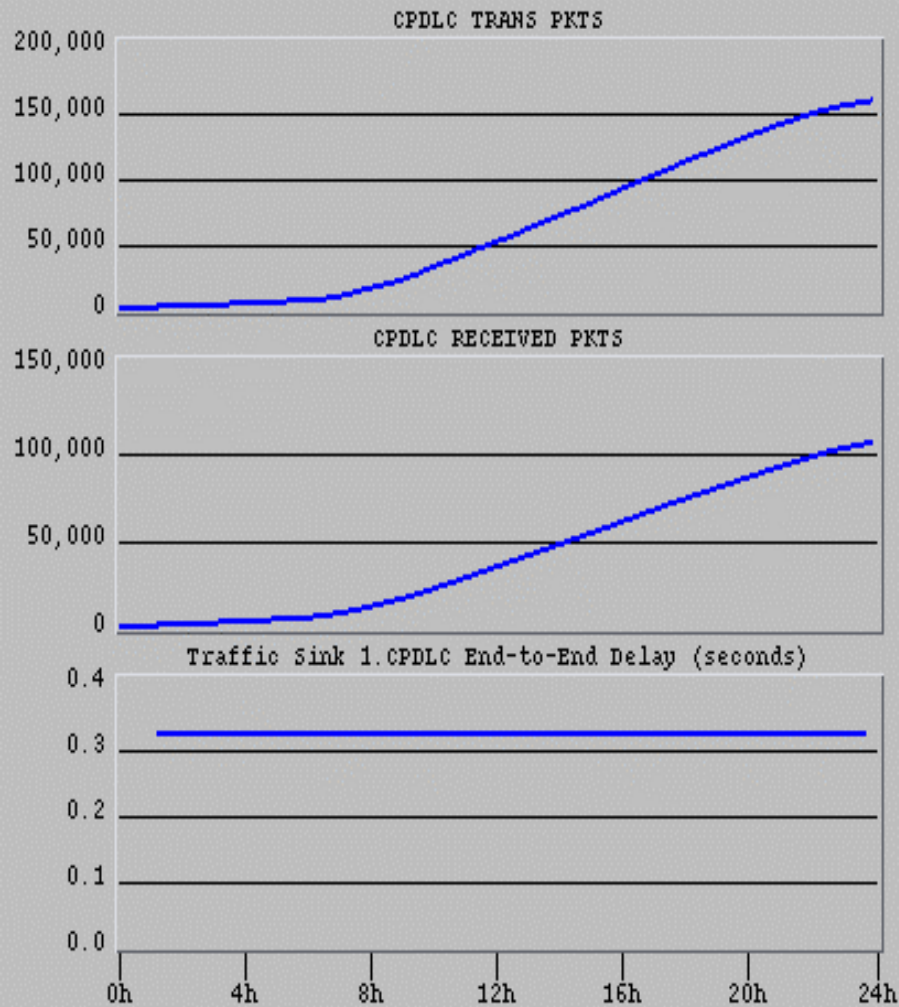


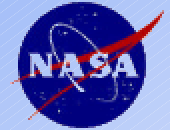
ETE Delay (I & V, D = 0.3184 s, D = 0.4039 s)





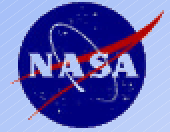
ETE Delay (III & VI, $D = 0.3188$ s, $D = 0.5772$ s)





Analysis

- A retransmission analysis reveals that if D is the mean ETE delay for a PCSMA network, then $D' > D/(1 - p)$ is the mean ETE delay for a CSMA (VDL-2) network, where “ p ” is the overall probability of a collision.
- “ p ” for simulations (I – III) is 11.4%, 20.5%, and 33.4%, yielding respective delay improvements over a comparable VDL-2 simulation of at least 12.9%, 25.8%, and 50.2%.
- A similar analysis involving 90 planes converging on a single ground station reveals that PCSMA gives a minimum of 20% delay improvement over VDL-2.
- Prioritized CSMA works and is probably comparable, if not better than, VDL-3 in terms of latency performance.



Future Research

- A large network has been constructed for this simulation. It may also be used for a simulation of VDL-3, which may be compared to these baseline simulations of PCSMA.
- A smaller CPDLC message size of 5,000 bits was used so that much higher data frequencies could be used and still obtain reasonable latencies.
- Plans are underway to expand the number of daily flights to between 5,000 and 10,000, and to use more precise message sizes and frequencies.
- We intend using versions of this network as a foundation for simulations involving ground station gap analysis and resolution through satellite communications.