Data Communications Performance of AOCDL and AUTOMET Over a VDL Mode 2 Link

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Airline Operational Control Data Link (AOCDL) is a service that allows for downlink of in-flight data to help an airline operate efficiently. Automated Meteorological Transmission (AUTOMET) is a weather reporting system that provides forecasts and atmospheric conditions to pilots during flight. These are two examples of new or extended services that will be enabled by implementation of the ATN and its digital air/ground communications data links. One of the possible data links identified for these services is VDL Mode 2.

This research focuses on the data link performance of AOCDL and AUTOMET services in a 2015 scenario using VDL Mode 2 as the data link. In the near term, it is expected that the Controller-Pilot Data Link Communication (CPDLC) and Decision Support System Data Link (DSSDL) services will also use the VDL Mode 2 link. CPDLC and DSSDL are high-priority services that communicate aircraft control information and require low end-to-end delays for safety. VDL Mode 3, which is the preferred link for these services because it provides priority-based link access, will not be deployed in time for earlier implementations of these services to use. As such, the research also investigates the impact of CPDLC and DSSDL services on the same VDL link as AOCDL and AUTOMET.

Performance of these services over the data link will be separately examined for the airport, terminal, and en route domains. OPNET simulations are performed for each domain. The number of aircraft for each domain is representative of the expected peak aircraft in 2015. Results are collected during a steady-state condition, with aircraft neither entering nor exiting the domain. The duration of the steady state is chosen such that enough samples can be collected to be considered statistically significant. The performance in a multiple-domain setting that may be more representative of a real-world implementation will also be investigated in simulation using the same procedures as those for the domain simulations.

The study explores the services in terms of the traffic load they present to the VDL Mode 2 radio. The amount of load each service contributes to the data link will be shown for each domain. The end-to-end delays for each service will be discussed. Data link metrics such as subnetwork and queuing delays, channel utilization, and protocol overhead will be used to show the impact of these services on VDL Mode 2. All results will be presented both with and without the inclusion of CPDLC and DSSDL services.

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Study Overview

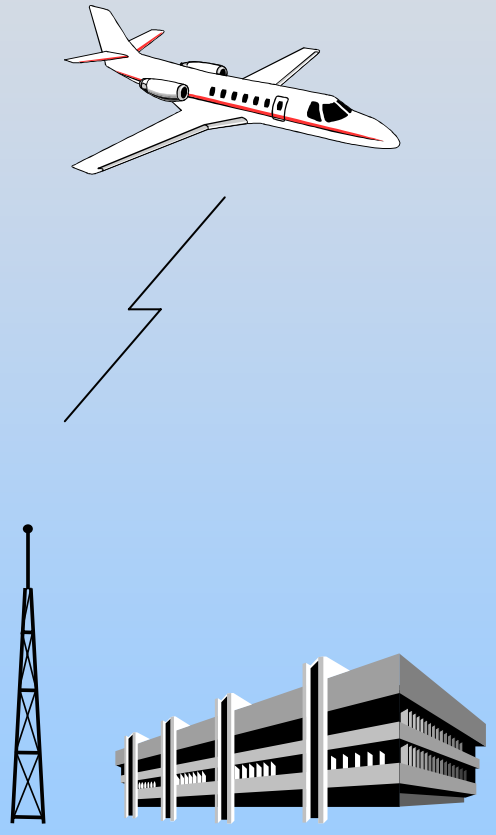
Funded by the Advanced Communications for Air Traffic Management project at NASA. The AC/ATM project is tasked with researching systems to provide the improved performance and increased capacity required for future air traffic management concepts.

Objectives:

- To study the AOCDL and AUTOMET services in the airport, terminal, and en route domains using VDL Mode 2 as the data link and determine expected delays in a 2015 scenario.
- To determine if AOCDL and AUTOMET services can share a single VDL Mode 2 channel with CPDLC and DSSDL.

VDL Mode 2 Overview

- VHF Digital Link (VDL)
- Provides reliable data communication with a connection-oriented data link protocol
- Medium access by p-persistent Carrier Sense Multiple Access (CSMA)
- Uses the Aeronautical VHF Band (118 - 137 MHz)
- D8PSK modulation, 31.5 kbps data rate



Service Overview

Airline Operational Control Data Link (AOCDL)

- Downlink of in-flight data to improve airline efficiency
  - Flight Status
  - Position reporting
- Routine service

Automated Meteorological Transmission (AUTOMET)

- Downlink meteorological information to improve weather reports and forecasts.
  - Wind, temperature, water vapor
- Routine service

Service Overview (cont)

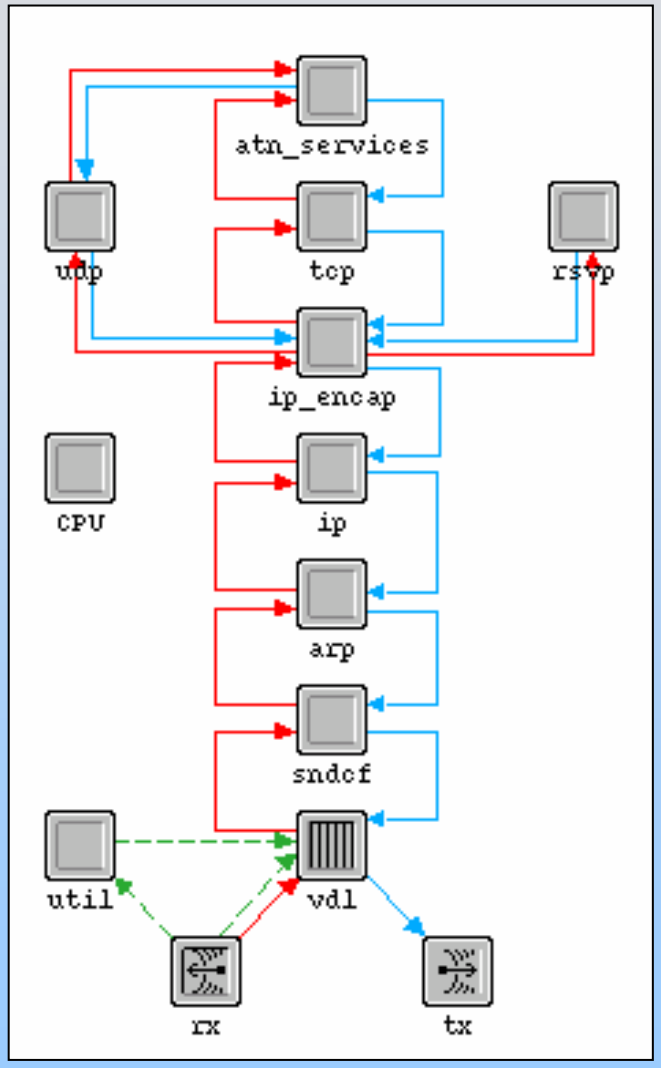
Controller-Pilot Data Link Communications (CPDLC)

- Digital messages for clearances and flight plan modifications
- Critical service
- VDL Mode 2 may be used in near term

Decision Support System Data Link (DSSDL)

- Communication of parameters to optimize decision
- Essential service
- VDL Mode 2 may be used in near term

Simulation Model



Aircraft and ground node model

Combination of OPNET-supplied and custom models

Uses IP protocol stack in place of ATN protocols

Models services by statistical generation of message sizes and inter-arrival times

Models VDL MAC and DLS sublayers in detail with adjustable parameters

Does not simulate aircraft or ground-based networks

Domain Parameters

Airport Domain

- Duration: 10 Minutes
- Peak aircraft: 192

Terminal Domain

- Duration: 10 minutes
- Peak aircraft: 137

En Route Domain

- Duration: 50 minutes
- Peak aircraft: 500

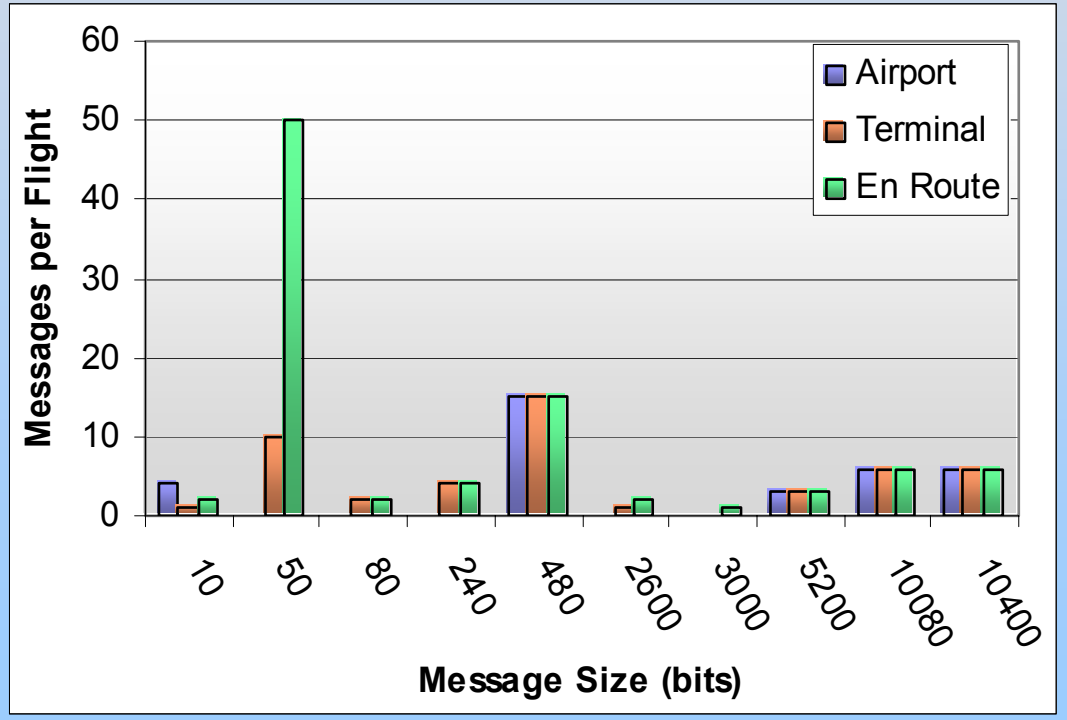
AOCDL Model

AOCDL model for airport, terminal, and en route domains

Required end-to-end latency:

- 10 seconds

	AOCDL		
	Messages	Load (kb)	Load (bps)
Airport	34	145.7	242.8
Terminal	48	150.0	250.0
En Route	91	142.0	47.3



Peak Aircraft with AOCDL in 2015		
Airport	Terminal	En Route
25	18	66

Source: "Communications System Architecture Development for Air Traffic Management and Aviation Weather Information Dissemination" by ARINC, SAIC, and TRW.

AUTOMET Model

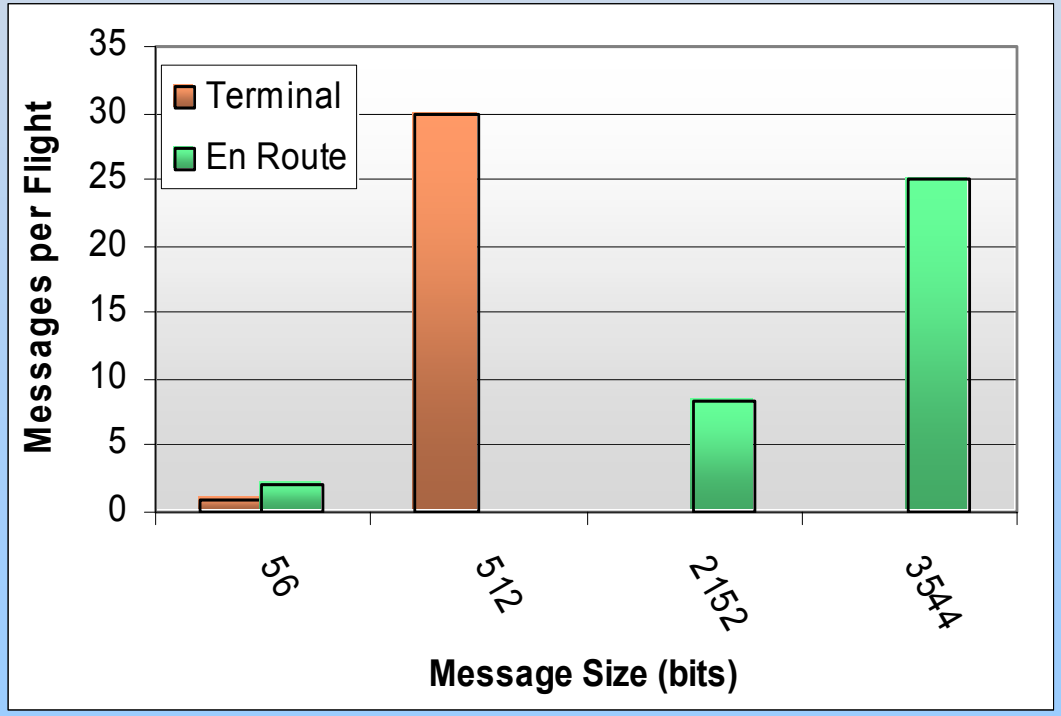
AUTOMET Model for terminal and en route domains

AUTOMET messages not sent in airport domain

Required end-to-end latency:

- 10 seconds

	AUTOMET		
	Messages	Load (kb)	Load (bps)
Terminal	31	15.4	25.7
En Route	35	106.6	35.3



Peak Aircraft with AUTOMET in 2015		
Airport	Terminal	En Route
N/A	87	314

Source: "Communications System Architecture Development for Air Traffic Management and Aviation Weather Information Dissemination" by ARINC, SAIC, and TRW.

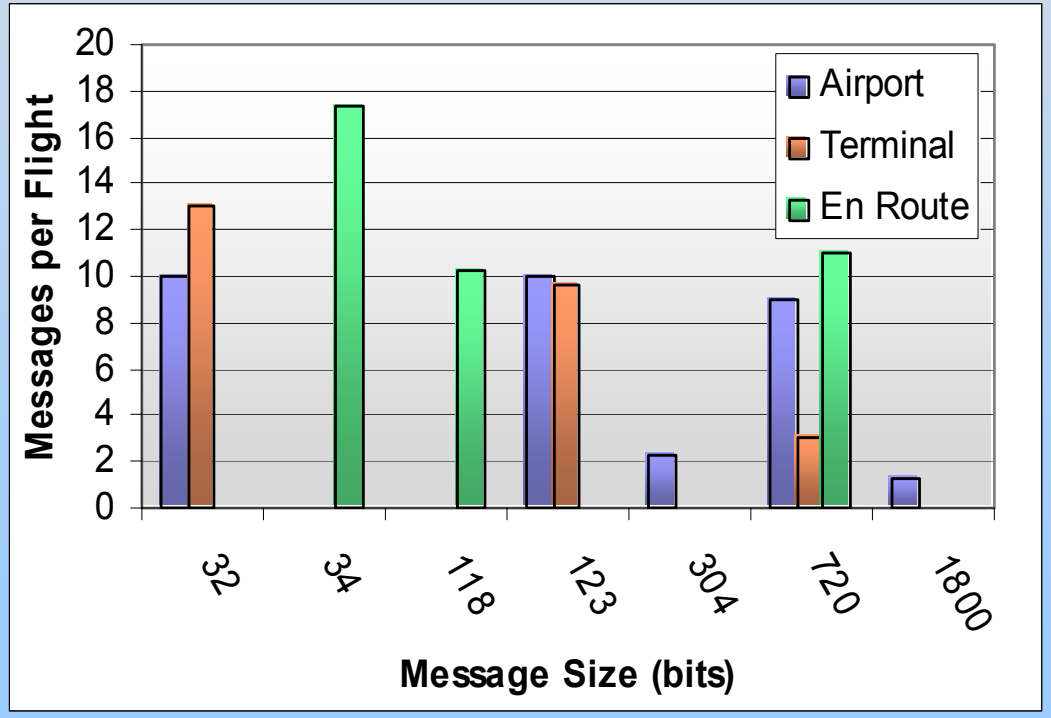
CPDLC Model

CPDLC Model for airport, terminal, and en route domains

Required end-to-end latency:

- 1 second

	CPDLC		
	Messages	Load (kb)	Load (bps)
Airport	32	10.9	18.2
Terminal	26	3.8	6.3
En Route	39	9.7	3.2



Peak Aircraft with CPDLC in 2015		
Airport	Terminal	En Route
125	90	327

Source: "Communications System Architecture Development for Air Traffic Management and Aviation Weather Information Dissemination" by ARINC, SAIC, and TRW.

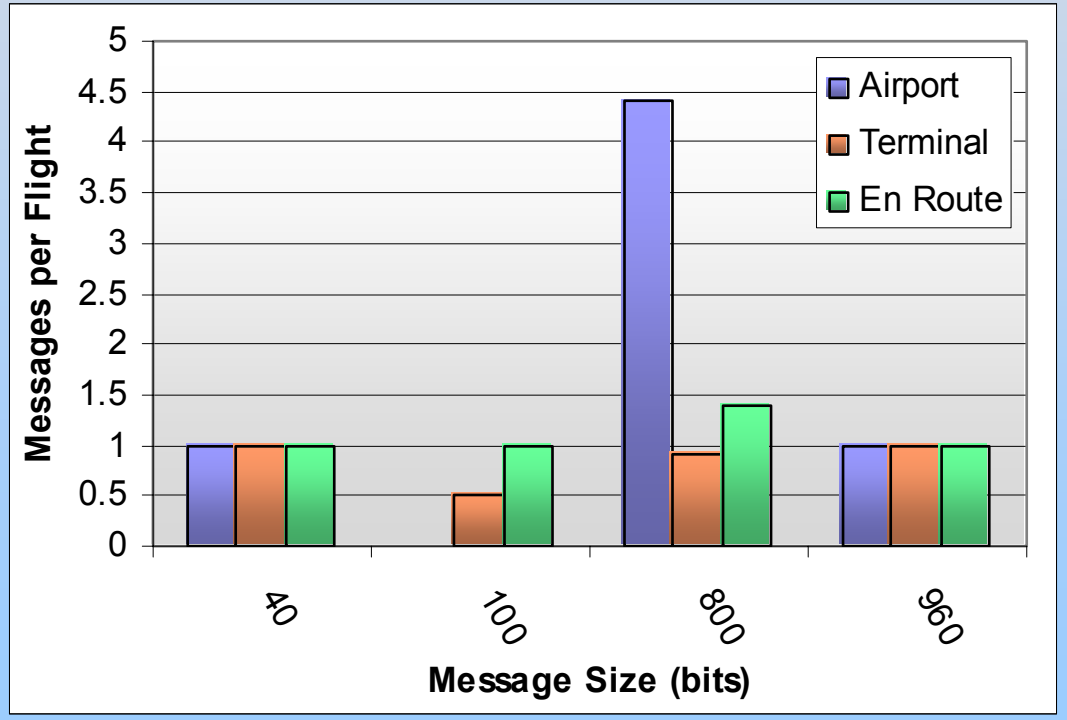
DSSDL Model

DSSDL model for airport, terminal, and en route domains

Required end-to-end latency:

- 1 second

	DSSDL		
	Messages	Load (kb)	Load (bps)
Airport	6	4.5	7.5
Terminal	3	1.8	3
En Route	4	2.2	0.7



Peak Aircraft with DSSDL in 2015		
Airport	Terminal	En Route
56	40	145

Source: "Communications System Architecture Development for Air Traffic Management and Aviation Weather Information Dissemination" by ARINC, SAIC, and TRW.

Simulation Parameters

VDL Mode 2 parameters optimized for heavy traffic load to produce lowest delays

- Lower persistence
- Shorter back-off delay
- Smaller transmit window size
- Longer retransmission delay

Parameters vary by domain

- Optimal back-off delay dependent upon propagation delay

Simulations slowly increase the number of aircraft to the specified number for each service. Data is taken only when all aircraft are in the subnetwork

AOCDL Performance

AOCDL delays within limits in all domains.

VDL Mode 2 can handle the load presented in each domain.

		Airport	Terminal	En Route
Service Load		6.5 kbps	4.7 kbps	3.6 kbps
Service Throughput		6.5 kbps	4.7 kbps	3.6 kbps
Link Throughput		8.9 kbps	6.7 kbps	5.6 kbps
Link Utilization		28.5 %	21.4 %	17.9 %
Mean Delay	uplink	0.14 s	0.12 s	0.21 s
	downlink	0.40 s	0.25 s	0.28 s
95% Delay	uplink	0.44 s	0.38 s	0.49 s
	downlink	0.78 s	0.61 s	0.70 s

AUTOMET Performance

AUTOMET delays within limits in both domains.

VDL Mode 2 can handle the load presented in each domain.

		Terminal	En Route
Service Load		2.2 kbps	11.3 kbps
Service Throughput		2.2 kbps	11.3 kbps
Link Throughput		6.5 kbps	15.0 kbps
Link Utilization		20.8 %	49.4 %
Mean Delay	uplink	0.05 s	0.39 s
	downlink	0.08 s	0.57 s
95% Delay	uplink	0.11 s	1.0 s
	downlink	0.13 s	2.1 s

Multiple Services

Increase efficiency by using multiple services on a single VDL channel

Combinations:

- AOCDL and AUTOMET
- CPDLC and DSSDL
- CPDLC, DSSDL, and AOCDL
- CPDLC, DSSDL, and AUTOMET

Assumptions:

- All aircraft are not identically equipped
- Aircraft may be equipped with more than 1 service

AOCDL and AUTOMET

AOCDL and AUTOMET delays within limits in terminal domain only.

VDL Mode 2 can handle the load presented by AOCDL and AUTOMET in terminal domain.

VDL Mode 2 cannot handle the load in the en route domain.

		Terminal	En Route
Service Load		7.1 kbps	15.0 kbps
Service Throughput		7.1 kbps	10.1 kbps
Link Throughput		13.4 kbps	19.3 kbps
Link Utilization		43.8 %	97.4 %
Mean Delay	uplink	0.18 s	-
	downlink	0.23 s	-
95% Delay	uplink	0.60 s	-
	downlink	0.79 s	-

CPDLC and DSSDL Performance

CPDLC and DSSDL delays within limits in all domains.

VDL Mode 2 can handle the load presented in each domain.

		Airport	Terminal	En Route
Service Load		2.7 kbps	0.7 kbps	1.2 kbps
Service Throughput		2.7 kbps	0.7 kbps	1.2 kbps
Link Throughput		9.6 kbps	4.4 kbps	5.2 kbps
Link Utilization		30.4 %	14.1 %	16.5 %
Mean Delay	uplink	0.07 s	0.06 s	0.19 s
	downlink	0.07 s	0.06 s	0.21 s
95% Delay	uplink	0.14 s	0.11 s	0.40 s
	downlink	0.14 s	0.11 s	0.42 s

CPDLC, DSSDL, and AOCDL

CPDLC, DSSDL, and AOCDL delays within limits in terminal domain only.

VDL Mode 2 can handle the load presented in each domain.

VDL Mode 2 could not meet the delay requirements for CPDLC and DSSDL in the airport and en route domains.

		Airport	Terminal	En Route
Service Load		8.9 kbps	5.5 kbps	4.7 kbps
Service Throughput		8.9 kbps	5.5 kbps	4.7 kbps
Link Throughput		18.6 kbps	11.3 kbps	10.5 kbps
Link Utilization		62.2 %	36.5 %	34.4 %
Mean Delay	uplink	0.53 s	0.17 s	0.32 s
	downlink	0.67 s	0.22 s	0.39 s
95% Delay	uplink	2.3 s	0.51 s	0.79 s
	downlink	2.9 s	0.69 s	1.5 s

CPDLC, DSSDL, and AUTOMET

CPDLC, DSSDL, and AUTOMET delays within limits in terminal domain only.

VDL Mode 2 can handle the load presented in terminal domain.

VDL Mode 2 could not support the load presented in the en route domain.

		Terminal	En Route
Service Load		2.9 kbps	12.7 kbps
Service Throughput		2.9 kbps	9.4 kbps
Link Throughput		10.8 kbps	19.6 kbps
Link Utilization		34.4 %	97.1 %
Mean Delay	uplink	0.08 s	-
	downlink	0.10 s	-
95% Delay	uplink	0.14 s	-
	downlink	0.17 s	-

Multiple Domains

Increase efficiency by serving multiple domains on a single VDL channel

Combinations:

- AOCDL in airport, terminal, and en route
- AUTOMET in terminal and en route
- AOCDL and AUTOMET in the airport and terminal
- CPDLC and DSSDL in airport, terminal, and en route
- CPDLC, DSSDL, and AUTOMET in airport and terminal

Assumptions:

- All domains handled by a single ground station
- All aircraft are not identically equipped

AOCDL

AOCDL delays within limits for all domain combinations.

VDL Mode 2 can support AOCDL in the airport, terminal, and en route domains simultaneously.

		Airport + Terminal	Terminal + En Route	All Domains
Service Load		11.3 kbps	8.3 kbps	14.5 kbps
Service Throughput		11.3 kbps	8.3 kbps	14.5 kbps
Link Throughput		17.5 kbps	11.8 kbps	19.7 kbps
Link Utilization		57.5 %	38.4 %	66.3 %
Mean Delay	uplink	0.58 s	0.34 s	0.93 s
	downlink	0.83 s	0.48 s	1.5 s
95% Delay	uplink	2.5 s	0.90 s	3.5 s
	downlink	3.1 s	1.4 s	6.9 s

AUTOMET

The terminal and en route domain combination is the only possible combination for AUTOMET.

VDL Mode 2 could not handle the load provided by AUTOMET in the combined terminal and en route domains.

		Terminal + En Route
Service Load		13.5 kbps
Service Throughput		9.1 kbps
Link Throughput		18.7 kbps
Link Utilization		98.2 %
Mean Delay	uplink	-
	downlink	-
95% Delay	uplink	-
	downlink	-

AOCDL and AUTOMET

VDL Mode 2 can handle the load presented in the airport and terminal domains.

VDL Mode 2 could not meet the delay requirements for AOCDL and AUTOMET.

		Airport + Terminal
Service Load		13.3 kbps
Service Throughput		13.3 kbps
Link Throughput		23.2 kbps
Link Utilization		80.8 %
Mean Delay	uplink	1.6 s
	downlink	2.5 s
95% Delay	uplink	8.0 s
	downlink	12.6 s

CPDLC and DSSDL

VDL Mode 2 can handle the load presented in all domains.

VDL Mode 2 can support CPDLC and DSSDL in the combined airport and terminal and terminal and en route domains, but not all simultaneously.

		Airport + Terminal	Terminal + En Route	All Domains
Service Load		3.3 kbps	1.7 kbps	4.5 kbps
Service Throughput		3.3 kbps	1.7 kbps	4.5 kbps
Link Throughput		13.7 kbps	9.3 kbps	19.1 kbps
Link Utilization		43.8 %	29.9 %	63.2 %
Mean Delay	uplink	0.10 s	0.26 s	1.1 s
	downlink	0.10 s	0.31 s	0.93 s
95% Delay	uplink	0.18 s	0.47 s	4.6 s
	downlink	0.19 s	0.62 s	4.9 s

CPDLC, DSSDL, and AUTOMET

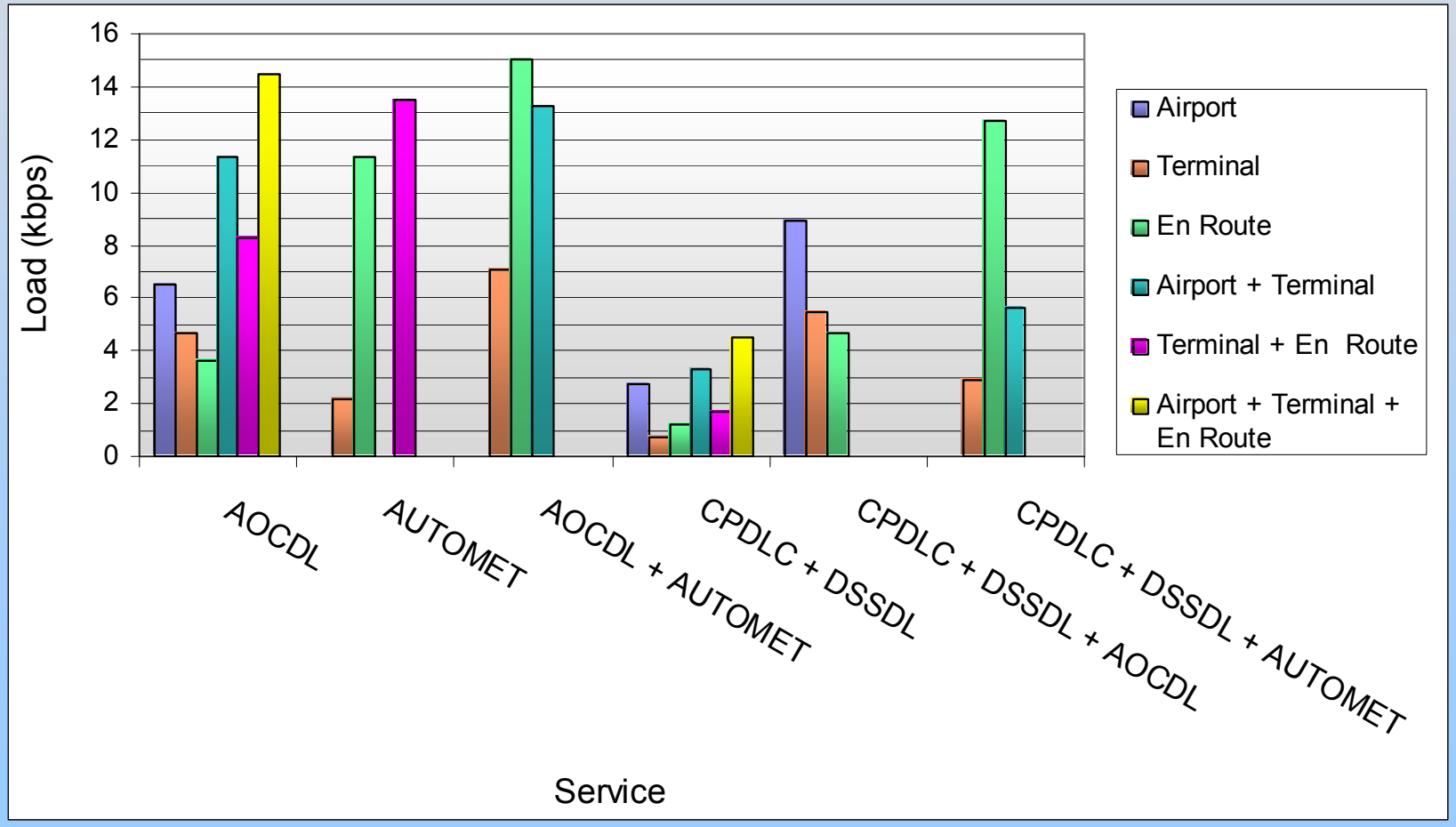
VDL Mode 2 can handle the load presented in the airport and terminal domains.

VDL Mode 2 could not meet the delay requirements for CPDLC and DSSDL

		Airport + Terminal
Service Load		5.6 kbps
Service Throughput		5.6 kbps
Link Throughput		19.9 kbps
Link Utilization		64.2 %
Mean Delay	uplink	0.18 s
	downlink	0.22 s
95% Delay	uplink	0.33 s
	downlink	1.5 s

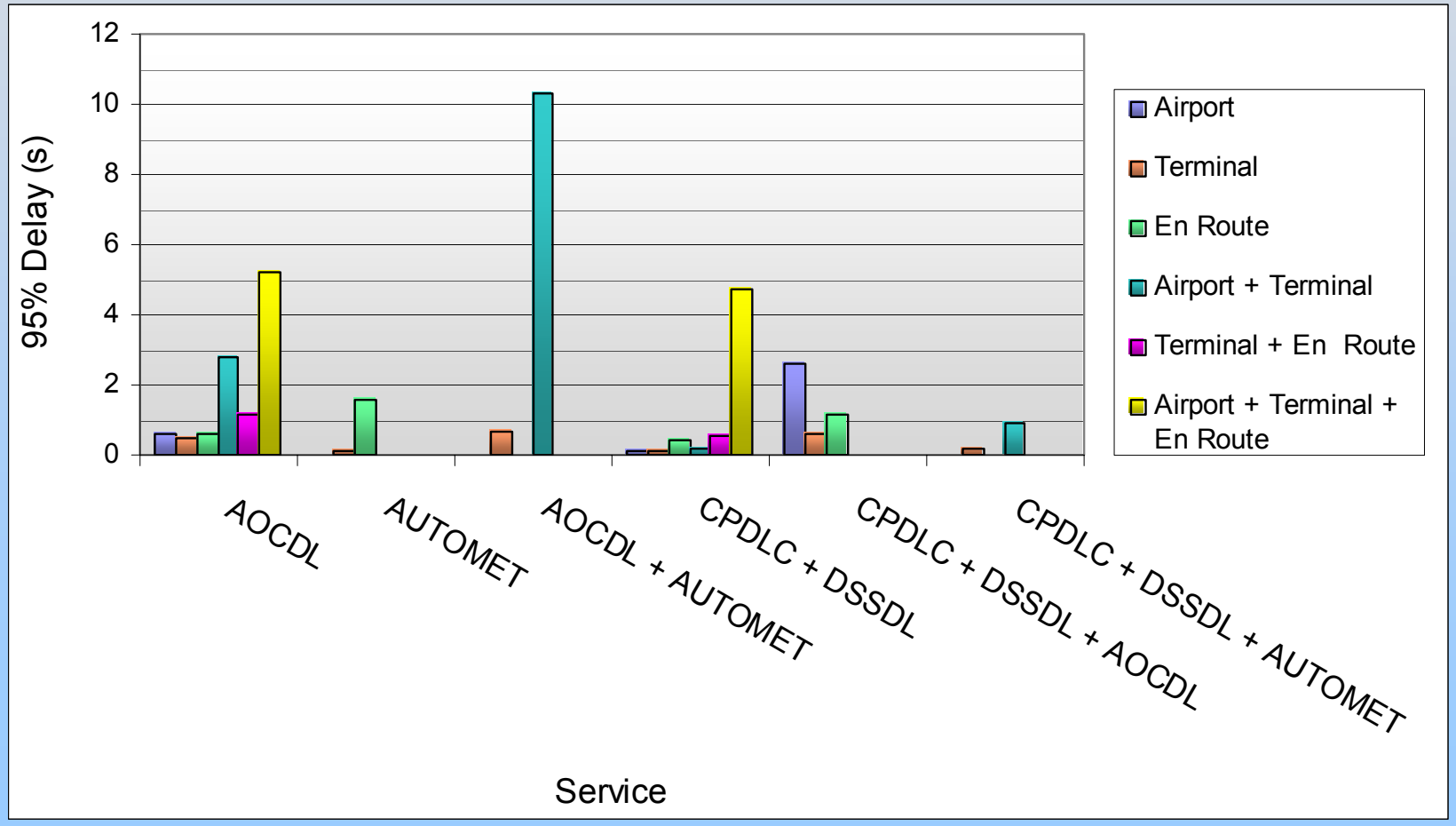
Overall Results

Service load presented to VDL Mode 2 for all performed simulations.



Overall Results (cont)

95th percentile delays for all performed simulations in which the service load was supported by VDL Mode 2



Conclusions

Factors influence the maximum capacity of a VDL Mode 2 channel

- Size of messages
- Number of aircraft
- Delay requirement

CPDLC and DSSDL can stress a VDL Mode 2 channel

- Not readily combinable with AOCDL and AUTOMET while meeting delay requirements

AOCDL and AUTOMET can't always be successfully combined on a single channel

- Exception - terminal domain

Some multi-domain combinations are possible

- AOCDL - all domains