ERLANG B/C LINK AVAILABILITY/BLOCKAGE FOR DATA AND VOICE OVER VDL MODE 3

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Project

- The work here was done as part of the Advanced Communications for **Air Traffic Management Project at NASA Glenn Research Center in Cleveland, Ohio**

Objective

- Look at blockage and availability of VHF Digital Link Mode 3 VDL-3
- Use future predicted voice and Controller Pilot Data Link Communications (CPDLC) application to obtain traffic loads
- Use Erlang B/C computations to obtain availability results for both voice and data
- Summarize findings and make recommendations

VDL-3 Specifications

VHF band for Aeronautical use	760*25 kHz total 524*25 kHz ATC only
Number of VDL-3 TDMA slots	3 max data/voice channels (3T) 4 max voice 2 voice,2 data 3 voice, 1 data (and 3 other configurations)
VHF channel bandwidth	25 kHz
M burst, M channel, or M slot	DL used for link access & status. UL use for timing configuration.
25 KHz channel data rate, with total overhead (coding, etc)	31.5 Kb/s
Modulation type	D8PSK
VDL TDMA slot period.	120 milliseconds total (4 TDMA slots) with M portion 30 milliseconds per TDMA slot (120ms /4 slots per frame)
Information bits/TDMA slot	496 data bits/ one TDMA slot 576 voice bits /one TDMA slot
Service data rate for data messages **μ** per TDMA slot	μ=496/120=4.13 Kbits/s (data) μ=576/120=4.8 Kbits/s (voice)
Tower/Airplane Transmit power	10 to 20 Watts
Required Signal to Co-channel interference ratio	20 db (26 db max, 14 db min)
CPDLC Frame Size	Using a crude average of 500 bits (includes overhead of 150%).

ATM Applications Traffic Loads

Based on predicted traffic by year 2015 (referenced from ARINC/TRW/SAIC report)

Domains are defined as 10 minutes flights in airport and terminal and 50 minutes in en route

Data Message Traffic for All Classes of Aircraft (K-bits per second)						
2015	**Airport Uplink**	**Airport Downlink**	**Terminal Uplink**	**Terminal Downlink**	**En Route Uplink**	**En Route Downlink**
FIS	0.2	0.0	0.9	0.0	6.9	0.0
TIS	23.7	0.0	7.0	0.0	20.5	0.0
CPDLC	3.4	2.9	1.3	0.9	1.1	1.3
DSSDL	0.2	0.3	0.1	0.2	0.1	0.1
AOC	0.4	8.4	0.6	8.5	0.2	3.5
ADS Reporting	0.0	16.1	0.0	3.3	0.0	1.5
AUTOMET	0.0	0.0	0.0	4.4	0.0	6.2
APAXS	0.0	0.0	0.0	0.0	131.7	115.5

CPDLC and Voice data per aircraft

$\lambda \equiv$ application demand rates (data and voice) Obtained from [6] for year 2015 projected traffic loads. **Aircraft Peak traffic loads for year 2015 for all classes (1,2,3) (over a designated sector) [6]:** **192 aircraft for airport** **137 aircraft for terminal** **500 aircraft for Enroute** **Note: airport and terminal domains are defined over a 10 minute period (600 seconds), while en route is defined over a 50 minute window.**	**For CPDLC data** 3.4 Kbits/s airport uplink, or 3.4/192 = 0.0177 Kbits/s per aircraft. 2.9 Kbits/s airport downlink, or 2.9/192 = 0.0151 Kbits/s per aircraft. 1.3 Kbits/s terminal uplink, or 1.3/137 = 0.0095 Kbits/s per aircraft. 0.9 Kbits/s terminal downlink. or 0.9/137 = 0.0066 Kbits/s per aircraft. 1.1 Kbits/s En Route uplink, or 1.1/500 = 0.0022 Kbits/s per aircraft. 1.3 Kbits/s En Route downlink, or 1.3/500 = 0.0026 Kbits/s per aircraft. **Digital Voice:** 23.0 Kbits/s airport uplink, or 23/192 = 0.1198 Kbits/s per aircraft. 10.56 Kbits/s airport downlink, or 10.56/192 = 0.0550 Kbits/s per aircraft 4.8 Kbits/s terminal uplink,or 4.8/137 = 0.0350 Kbits/s per aircraft 4.8 Kbits/s terminal downlink, or 4.8/137 = 0.0350 Kbits/s per aircraft 10.56 Kbits/s En Route uplink, or 10.56/500 = 0.0211 Kbits/s per aircraft 2.88 kbits/s En Route downlink, or 2.88/500 = 0.0058 Kbits/s per aircraft.

VDL-3 Access Channel

Service data rate for request messages **μ** per M burst slot	μ=0.2 Kbits/sec with up to 10 M bursts available for 3T configuration and from 2 to 3 for 1v1d group as an example
Request message Frame Size	48 bits
Request message data rates in the down link direction	Airport domain 3.1488 bits/sec per aircraft Terminal domain 1.5456 bit/sec per aircraft En Route domain 0.4608 bits/sec per aircraft

-Only downlink requests for time slots occur from the aircraft to the ground whenever a CPDLC packet need to be sent.

-Also, for every uplink CPDLC message from the ground, the aircraft transport protocol layer needs to send an acknowledgment, and hence needs to send a request for a time slot.

-Therefore frequency can be obtained by taking the combined down link and uplink CPDLC data rates in each domain, and dividing by a 500 bit CPDLC average packet size (for a conservative result).

-For example in en route, we would have (0.0022e3+0.0026e3)/500=0.0096 CPDLC messages per second or at least 0.0096 request messages per second per aircraft. Using the 48 bit request message size this gives us a rate of 0.0096*48=0.4608 bits/sec.

Erlang B for voice and access

- Erlang B for voice and Access channels using M/M/C loss model. No queue

$$B(c,a) = \left(\frac{\frac{a^c}{c!}}{\sum_{n=0}^{c} \frac{a^n}{n!}} \right)$$

Probability of voice call or packet being blocked from using (c) channels

$$a = \lambda / \mu$$

Average traffic intensity in erlang (ratio of average demand rate over average service rate)

Erlang C for CPDLC data portion

- Erlang C for data portion of VDL-3: Packets able to queue with c available service channels

$$P(N \geq c) = C(c,a) = \frac{\frac{a^c}{c!}}{\left((1-\rho)\sum_{n=0}^{c-1} \frac{a^n}{n!} + \frac{a^c}{c!} \right)}$$

Probability of packets Queuing in system (i.e. all channels busy)

$$L_q = \frac{\rho C(c,a)}{1-\rho}$$

Queue size

$$W_q(t) = 1 - C(c,a)\exp^{-\mu t(c-a)}$$

Wait time in queue

$$W(t) = \begin{cases} a \neq c-1 \\ 1 - \frac{(a-c+Wq(o))}{(a+1-c)}\exp^{-\mu t} - \frac{C(c,a)}{(a+1-c)}\exp^{-c\mu t(1-\rho)} \\ \\ a = c-1 \\ 1-(1+C(c,a)\mu t)\exp^{-\mu t} \end{cases}$$

Wait time in System

Availability of channels

- Availability is defined as the probability that at least one empty TDMA slot is available when a packet is ready to be sent or voice call made:

$$A_B = 1 - B(c, a)$$

- A more appropriate availability for data is defined as the:

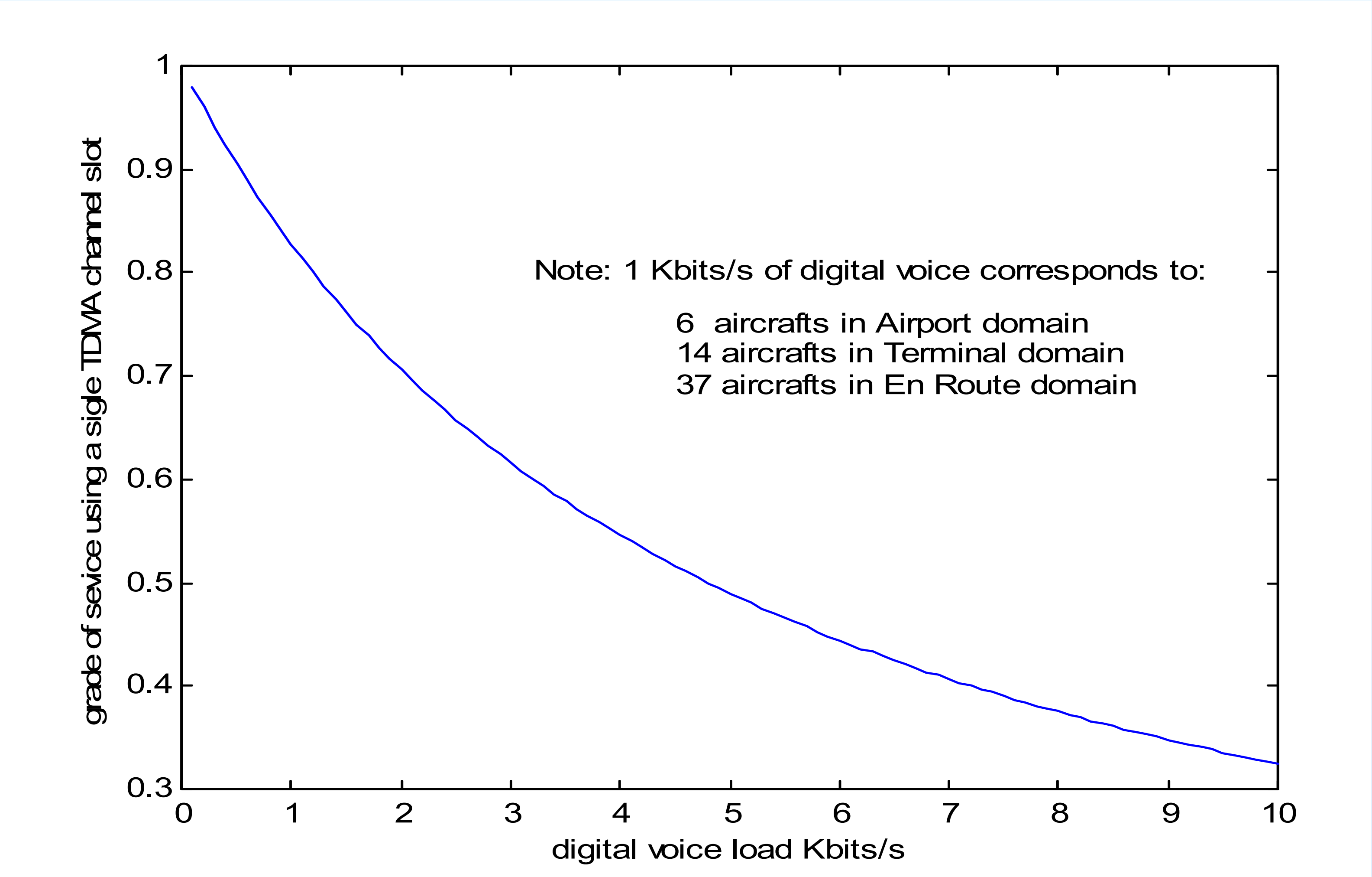
  Probability packet has to wait in the system for lesser than the outage definition time T_{od} (even if channels are not all used):

$$A_{cw} = 1 - W(T_{od})$$

- A combined probability can also be utilized as product:

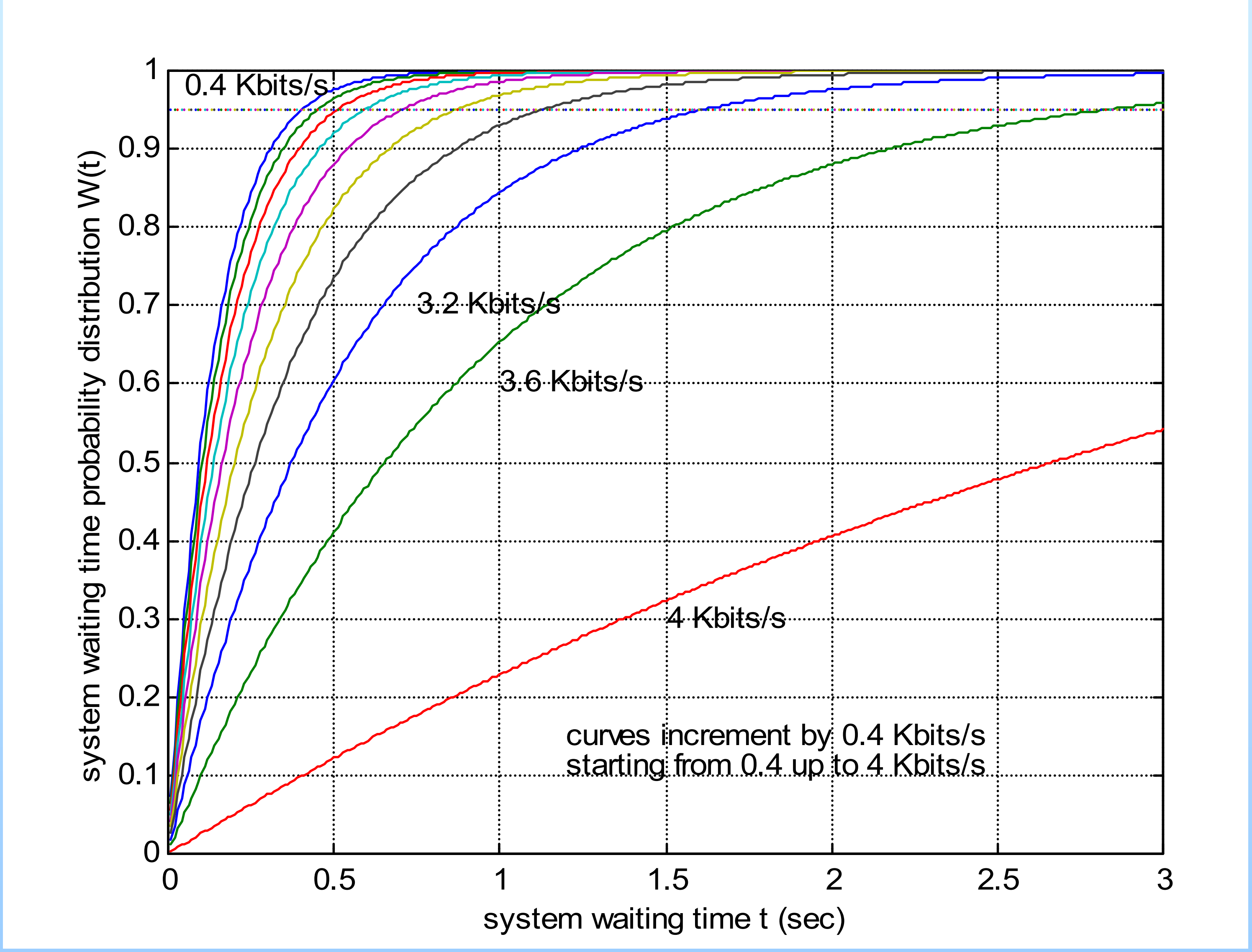
$$A_{total} = A_B A_{CW} \ldots$$

Availability of Voice



Availability of voice services for a range of data rate using Erlang B using a single TDMA time slot. Sharing 2 channel (works only if other mechanisms exist to filter out sectors or each controller) increase number of supported aircrafts by 4 to 6 time. Having 2 independent channels (normal case for two controllers) gives 2 times the capacity of that shown above (linear increase)

Availability of CPDLC data over VDL-3



System waiting time distribution curves W(t) for a single data slot channel (c=1), with a CPDLC frame size of 500 bits

Availability of CPDLC data over VDL-3

- Observation of Figure 2 indicates that a waiting time in the system of less that 1 second and with a 0.95 probability can be achieved with data loads up to 6*0.4=2.4 Kbits/sec (sixth curve from left to right).

- Using the uplink and downlink data rates per aircraft shown earlier, we can determine an ideal capacity of a single data TDMA slot.

- For example 2.4 Kbits/sec corresponds to:

airport 2.4/(0.0177+0.0151)=73 aircraft
terminal 2.4/(0.0095+0.0066)=149 aircraft
en route 2.4/(0.0022+0.0026)=500 aircraft.

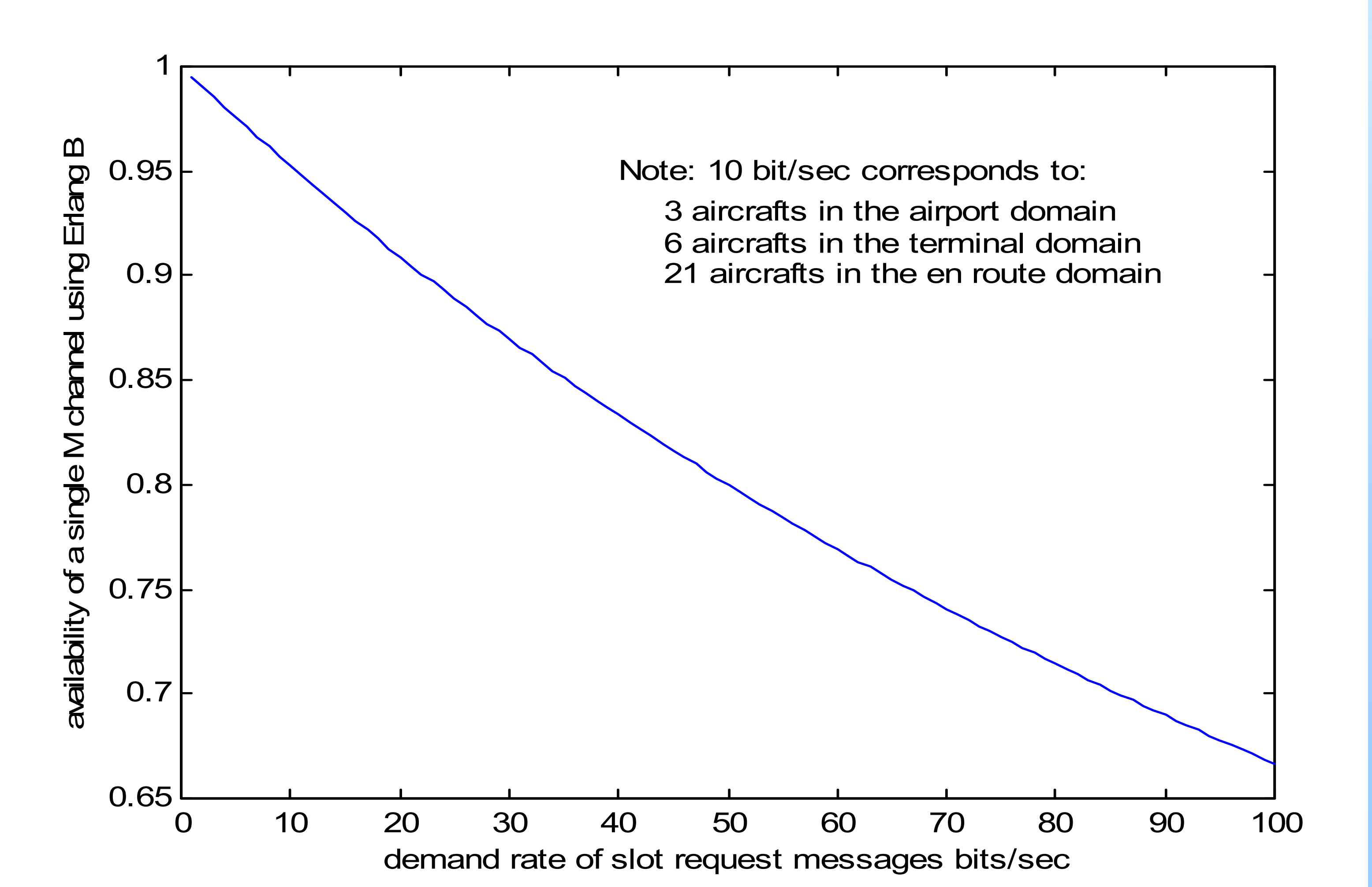
A lot of capacity !

Using more than one channel (up to three data) increases that capacity by many folds and if message sizes are smaller that also increases capacity, but 500 bits is a good medium between largest and smallest.

Availability of access Management (M) channels

-Uses Erlang B since packets do not queue. Curve is per one M channel (up to 10 are available depending on configuration, example 3T has up to 10 M channels).

-Aircrafts transmitter randomly sends request to M channels. Hence to measure capacity we assume parallel independent channels (as oppose to sharing which can produce much more capacity)



Availability of access Management (M) channels

- From Figure, a single M channel, at a 0.90 grade of service (or 10% chance of being blocked or colliding). we can have up to:

  6 aircraft accommodated in the airport domain
  12 aircraft accommodated in the terminal domain
  42 in the en route domain

  - Example a 2v2d configuration is used, then each group (or single controller group) will have 1 voice and 1 data channels (TDMA slots) with each containing an M burst logical channel. 12, 24, and 84 aircraft supported for airport, terminal, and en route domains under each controller

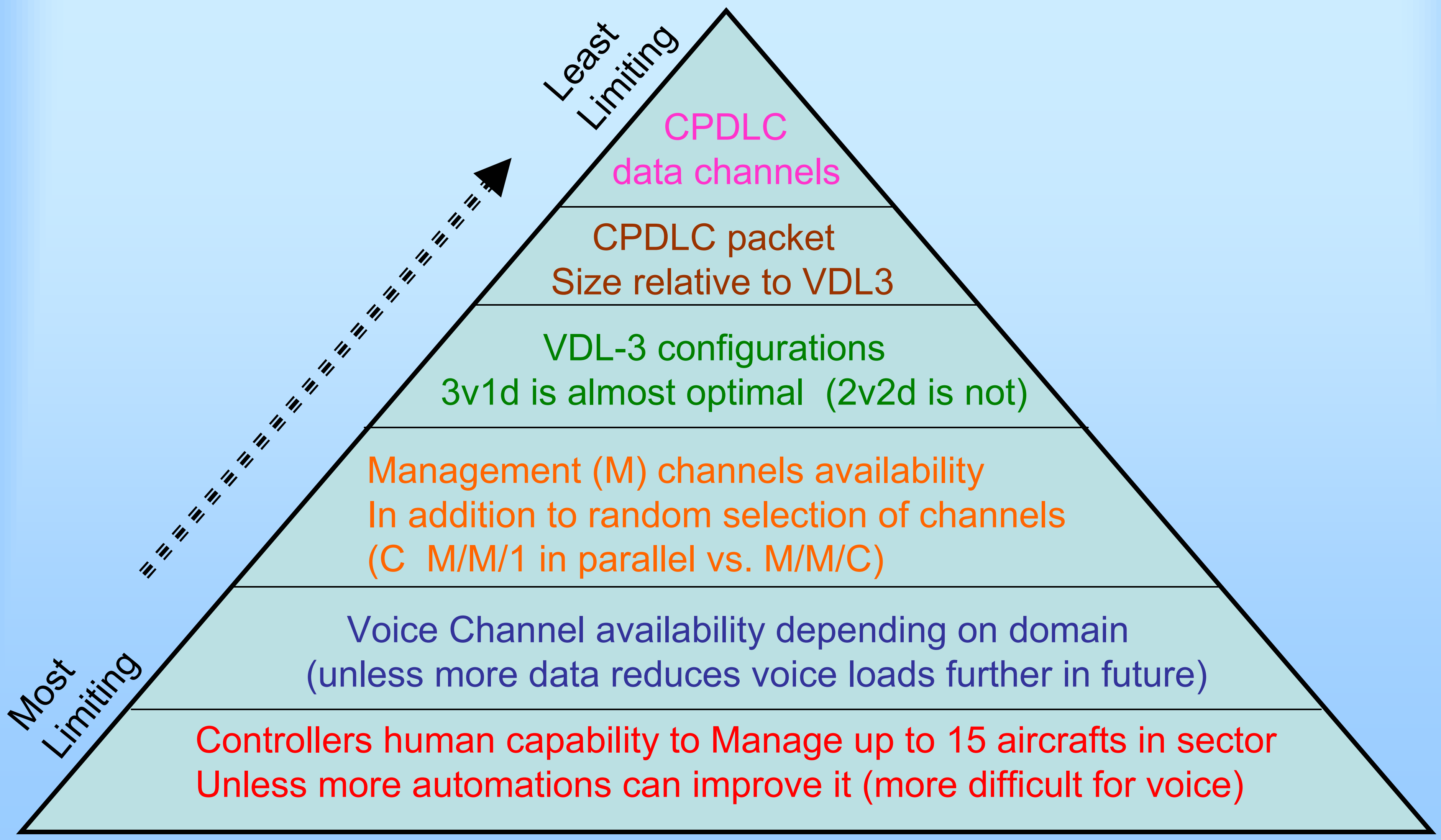
  - In 3T configuration have up to 10 channels leads to 60, 120, and 420 aircraft

Based on those results it is evident that the capabilities of the data service are limited by the access channels rather than by the CPDLC data portions.

Combined CPDLC data and Request Availability Analyses

- look at the probability of getting service within a total required time Tod.
- That would include the first try, plus the chance in the second try (if the first try was blocked), plus the third try (if the first two tries are blocked) and so on up to the time reaching its maximum allowed Tod.
- Use the product of the probability of getting access to the M channel with the probability that the service time will be less than Tod (or Tod-time for next try…etc)
- As the number of retries increases that reduces the access channel blockage
- However, as the number of allowable retries increases, that will also increase the request data traffic load which have the opposite effect of reducing the number of supported aircraft
- For example with a 0.95 requirement that data packets have to be received within 1 second time frame and up to two tries possible, with of 3 data channels and 8 M access channels, an approximate number of 25 to 35 aircraft is supported using worst case scenarios
- better number of aircraft than looking at the access channel alone, but a worse one based on the data channel alone as expected.

What are the limiting factors on Availability of VDL-3



Summary

- This study involved the computation of availability/blockage of voice and data over VDL Mode 3 data link.
- The Erlang B was used for the voice and M channels. Erlang C was used for the CPDLC data services
- Several parameters effecting availability studied: system wait time, range of service data, number of available TDMA logical channels, and packet size.
- The study looked at channels in terms of a single VDL-3 frequency link. Previous study looked at available frequency channels given Co-channel interference requirements can be linked with this study to show the overall system capacity and availability. Additional frequencies add to capacity
- More results can be obtained from study if needed
- Results showed limitations starting at controller and ending at CPDLC data channels capability
- Future studies can look into: priority queuing; more analyses of repeated requests; data slots and packet size optimality, Investigating unconventional ideas such as the advantages of reducing voice traffic, dynamic and data channel allocations via voice preemption; transport layer effects on loading M channels; ….. others.