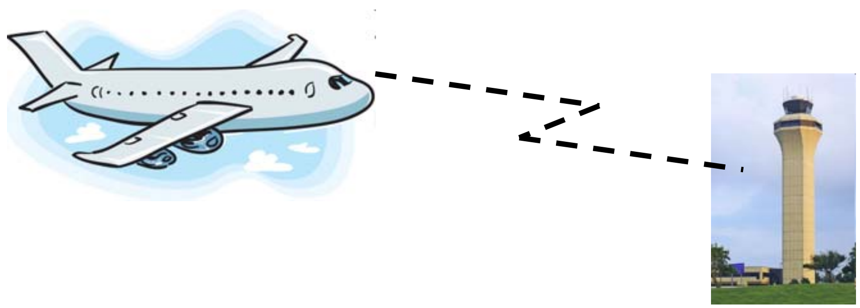
# Analysis of L-Band Digital Aeronautical Communication Systems: L-DACS1 and L-DACS2

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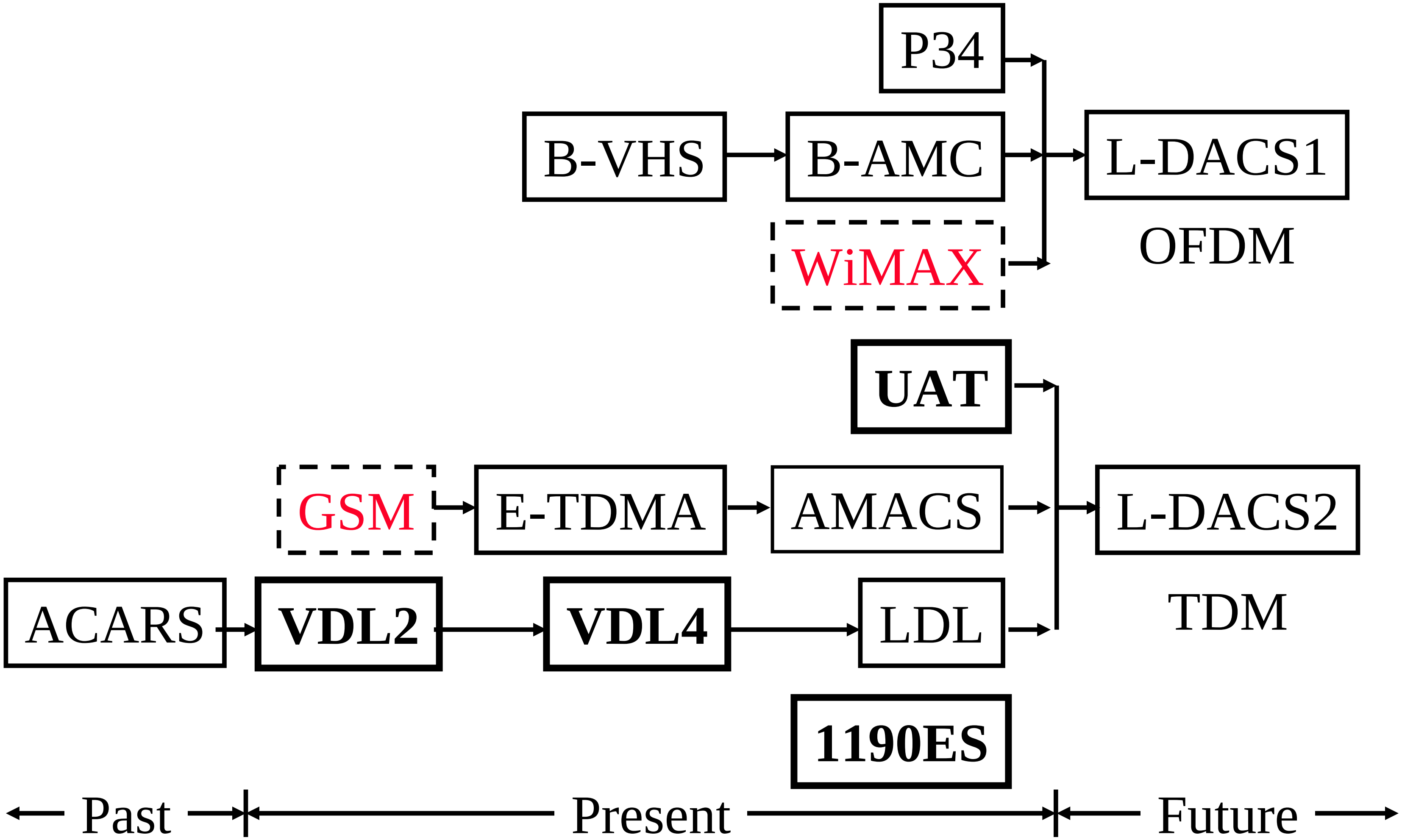
1. Evolution of Aeronautical Datalinks
2. L-Band Digital Aeronautical Communication System (L-DACS1 and LDAC2)
3. Functional Analysis
4. Interference Analysis
5. Performance Analysis

# Evolution of Aeronautical Datalinks



# Evolution of Aeronautical Datalinks (Cont)

- ACARS: Aircraft Communications Addressing and Reporting System. Developed in 1978. **VHF** and **HF**. Analog Radio
- VDL2: Digital link. In all aircrafts in Europe. 1994. VHS.
- VDL4: Added Aircraft-to-Aircraft. 2001. Limited deployment
- LDL: **L-Band** Digital Link. TDMA like GSM.
- E-TDMA: Extended **TDMA**. Hughes 1998. **Multi-QoS**
- AMACS: All purpose Multichannel Aviation Communication System. 2007. L-Band. Like GSM and E-TDMA.
- UAT: 981 MHz. 2002. One 16B or 32B message/aircraft/sec
- P34: EIA/TIA Project 34 for public safety radio. Covers 187.5 km. L-Band.
- B-VHS: MC-CDMA (**OFDMA**+CDMA). VHF. TDD.
- B-AMC: Broadband Aeronautical Multicarrier System. OFDMA. B-VHS in L-Band.

# L-DACS: Common Features

- L-band Digital Aeronautical Communications System
- Type 1 and Type 2
- Both designed for Airplane-to-ground station communications
- Airplane-to-airplane in future extensions
- Range: 200 nautical miles (nm)
  (1 nm =1 min latitude along meridian = 1.852 km =1.15 mile)
- Motion: 600 knots = 600 nm/h = Mach 1 at 25000 ft
- Capacity: 200 aircrafts
- Workload: 4.8 kbps Voice+Data
- All safety-related services
- Data=Departure clearance, digital airport terminal information, Oceanic clearance datalink service

# Issue 1: Modulation and Multiplexing

- Modulation:
    - Single Carrier
    - Multi-carrier
- Multiplexing:
    - Time division
    - Frequency division
    - Code division
    - Orthogonal Frequency Division

# L-DACS1

- OFDMA: Similar to WiMAX
- Multi-carrier: 50 carriers 9.76 kHz apart
- Use two channels of 498 kHz each

# L-DACS2

- Based on GSM
- GSM PHY, AMACS MAC, UAT Frame Structure
- Uses Gaussian Minimum Shift Keying (GMSK) modulation as in GSM
- GSM works at 900, 1800, 1900 MHz
  $\Rightarrow$ L-DACS2 is in lower L-band close to 900MHz
- Tested concept
- Price benefit of GSM components
- Uses basic GSM not, later enhanced versions like EDGE, GPRS, …
  These can be added later.

Ref: http://en.wikipedia.org/wiki/Gaussian_Minimum_Shift_Keying#Gaussian_minimum-shift_keying

# Single vs. Multi Carrier

- WiMAX, 11a/g/n use OFDM
- Advantages of OFDM:
  - Graceful degradation if excess delay
  - Robustness against frequency selective burst errors
  - Allows adaptive modulation and coding of subcarriers
  - Robust against narrowband interference (affecting only some subcarriers)
  - Allows pilot subcarriers for channel estimation

# L-DACS1: OFDM Parameters

- Subcarrier spacing: 9.76 kHz
  = Similar to WiMAX
- Guard Time Tg = 17.6 μs = 5.28 km

| **Parameter** | **Value** |
|---|---|
| Channel bandwidth B | 498 kHz |
| Length of FFT Nc | 64 |
| Used sub-carriers | 50 |
| Sub-carrier spacing (498/51 kHz) f | **9.76 kHz** |
| OFDM symbol duration with guard Tog | 120 μs |
| OFDM symbol duration w/o guard To | 102.4 μs |
| Overall guard time duration Tg | **17.6 μs** |
| OFDM symbols per data frame Ns | 54 |

# L-DACS1 Design Decisions

- Large number of carriers
  ⇒ Reduced subcarrier spacing
  ⇒ Increased inter-carrier interference due to Doppler spread

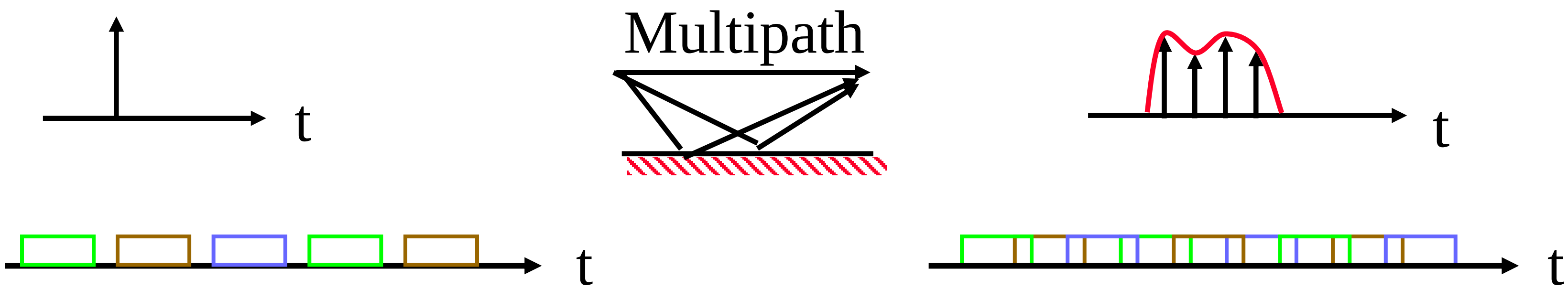
10 kHz spacing 20 kHz spacing


- Doppler causes carrier frequency shift:


- WiMAX use 10 kHz spacing
- Long Term Evolution (LTE) uses 15 kHz spacing to meet faster mobility

# L-DACS1 Design Decisions

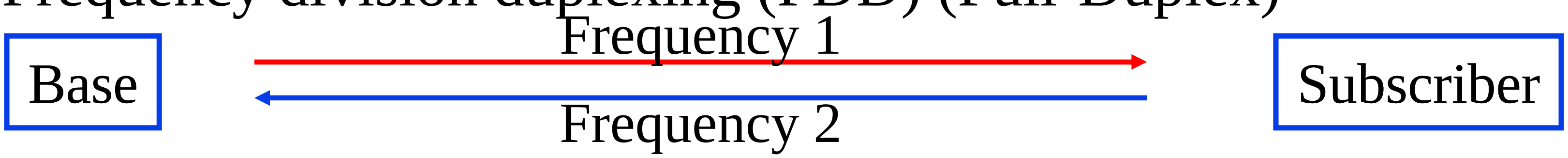
- Multipath causes symbols to expand:



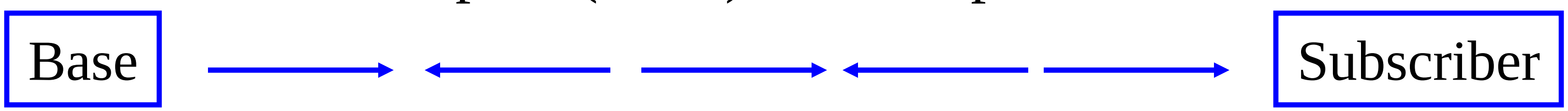

- Guard time duration Tg (Cyclic prefix) is designed to overcome this delay spread.
- 17.6 μs = 5.8 km path differential in L-DACS1
- LTE is designed with two CP lengths of 4.7 μs, 16.7 ms, and 33.3 ms (1.4km, 5 km, 10 km).

# Issue 2: Duplexing (TDD vs. FDD)

- L-DACS1 is FDD, L-DACS2 is TDD.
- Duplex = Bi-Directional Communication
- Frequency division duplexing (FDD) (Full-Duplex)




- Time division duplex (TDD): Half-duplex

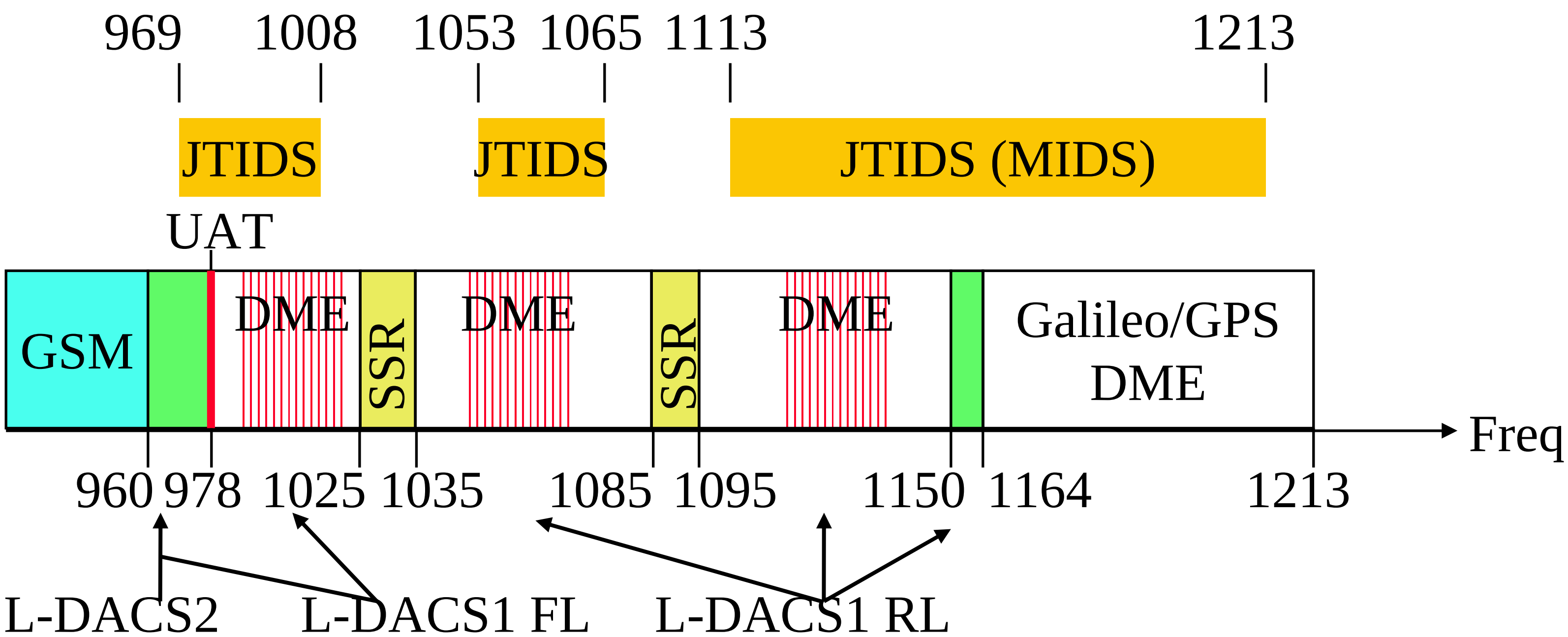



- Most WiMAX/LTE deployments will use TDD.
    - Allows more flexible sharing of DL/UL data rate
      Good for data
    - Does not require paired spectrum
    - Easy channel estimation ⇒ Simpler transceiver design
    - Con: All neighboring BS should synchronize

# Duplexing (cont)

- L-DACS1 FDD selection seems to be primarily because 1 MHz contiguous spectrum may not be available in L-band.
- Possible solution: Carrier-bonding used in the WiMAX v2 and in LTE

# L-Band Spectrum Usage




- L-DACS1 ⇒ 2x498.5 kHz FL in 985.5-1008.5MHz, RL in 1048.5-1071.5MHz, Duplex spacing 63 MHz

DME=Distance Measuring Equipment
JTIDS=Joint Tactical Information Distribution System
MIDS=Multifunction Information Distribution System
SSR=Secondary Surveillance Radar
GSM=Global System for Mobile Communications

- L-DACS2 ⇒ One 200 kHz channel in lower L-Band 960-975 MHz

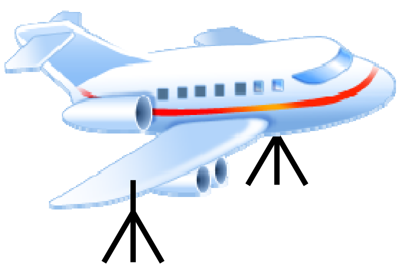
# Issue 3: Interference

**Interfering Technologies:**

1. Distance Measurement Equipment (DME)
2. Universal Access Transceiver (UAT)
3. 1090 Extended Squitter (ES)
4. Secondary Surveillance Radar (SSR)
5. Joint Tactical Information Distribution System (JTIDS)
6. Groupe Speciale Mobile (GSM)
7. Geostationary Navigation Satellite System (GNSS)

# DME

- Distance Measuring Equipment
- Ground DME markers transmit 1kW to 10 kW EIRP.
- Aircraft DME transmits 700W = 58.5 dBm
- Worst case is Aircraft DME to Aircraft L-DACS

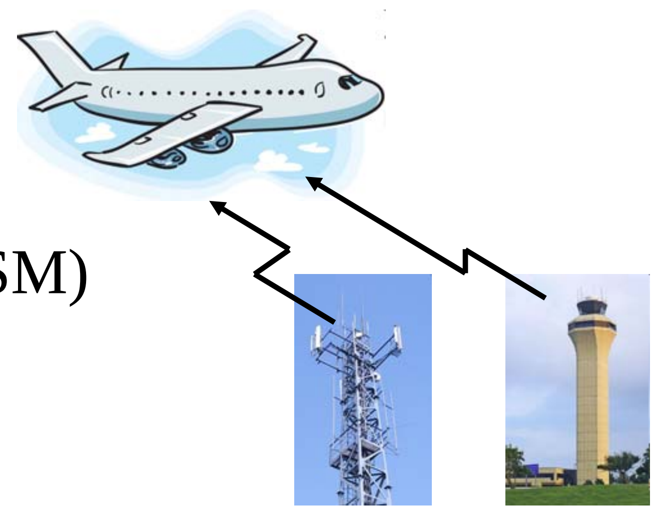


| | L-DACS |
|---|---|
| AS DME XMTR Power | 58.5 dBm |
| Path loss | -35 dB |
| Net Interference | 23.5 dBm |

- Same side of the aircraft or small aircrafts $\Rightarrow$ Even 35 dB isolation results in +23.5 dBm
- Need to design coordination

# GSM Interference

- Maximum allowed EIRP 62 dBm
  - 43 dB power + 19 dBi Antenna gain
  - 37 dB power + 25 dBi Antenna gain
- -80 dBc power at 6 MHz from the carrier
- GSM Interference:
  - L-DACS1 = -22dBm
  - L-DACS2= -10.8 dBm
    (L-DACS2 uses a band close to GSM)



# Performance Requirements

- Peak Instantaneous Aircrafts Counts (PIACs):

| Region | Year | APT | TMA | ENR | ORP |
|---|---|---|---|---|---|
| Europe | 2020 | | 16 | 24 | |
| US | 2020 | 200 | | 41 | 10 |
| Europe | 2030 | | 44 | 45 | |
| US | 2030 | 290 | | 95 | 34 |

APT = Airport
TMA = Terminal Maneuvering area
ENR = En route
ORP = Oceanic/Remote/Polar
AOA = Autonomous Operations Area

Ref: Communications Operating Concepts and Requirements (COCR) V2

# Performance Reqs (cont)

- Maximum Airspeed in Knots True Air Speed (KTAS)

| | APT | TMA | ENR | ORP | AOA |
|---|---|---|---|---|---|
| Phase 1 | 160 | 250 | 600 | 600 | |
| Phase 2 | 200 | 300 | 600 | 1215 | 540 |

- Most stringent capacity requirements in kbps:

| Phase | APT | TMA | ENR EU | ENR US | ORP | AOA |
|---|---|---|---|---|---|---|
| Phase 1 | 30 | 8 | 15 | 20 | 5 | |
| Phase 2 | 200 | 40 | 150 | 200 | 40 | 100 |

- Phase 2 begins in 2020. Requirements seem too low.

# Data Rate

- L-DACS1: QPSK1/2 - 64-QAM 3/4
  ⇒ FL (303-1373 kbps)
  + RL (220-1038 kbps) using 1 MHz
  ⇒ Spectral efficiency = 0.5 to 2.4 bps/Hz
- L-DACS2: 270.833 kbps (FL+RL) using 200 kHz
  ⇒ Spectral efficiency = 1.3 bps/Hz
  (Applies only for GSM cell sizes)
  Signal to noise ratio decreases by the $2^{nd}$ to $4^{th}$ power of distance

# Summary

1. L-DACS1 with OFDM is more scalable than L-DACS2 with single carrier modulation.
2. L-DACS1 also has better spectral efficiency because it can use adaptive modulation and coding (QPSK through 64 QAM).
3. Multi-carrier design of L-DACS1 is also more flexible in terms of spectrum placement.
4. Multi-carrier design of L-DACS1 is also more suitable for interference avoidance and co-existence than L-DACS2.
5. The TDD design of L-DACS2 is better suited for asymmetric data traffic than FDD design of L-DACS1.
6. The cyclic prefix and subcarrier spacing of L-DACS1 need to be analyzed to check if it will work at aircraft speeds.
7. GSM900 stations may cause significant interference with the L-DACS systems. Again L-DACS2 is more susceptible to such interference.

# Related Papers and Biography

- Raj Jain, Fred L. Templin, "**Datalink for Unmanned Aircraft Systems: Requirements, Challenges and Design Ideas**," AIAA Infotec@Aerospace Conference, Saint Louis, MO, March 2011, http://www1.cse.wustl.edu/~jain/papers/uas_dl.htm

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- **Biography**: Raj Jain is a Fellow of IEEE, a Fellow of ACM, a winner of ACM SIGCOMM Test of Time award, CDAC-ACCS Foundation Award 2009, Hind Rattan 2011 award, and ranks among the top 50 in Citeseer's list of Most Cited Authors in Computer Science. Dr. Jain is currently a Professor of Computer Science and Engineering at Washington University in St. Louis. Previously, he was one of the Co-founders of Nayna Networks, Inc - a next generation telecommunications systems company in San Jose, CA. He was a Senior Consulting Engineer at Digital Equipment Corporation in Littleton, Mass and then a professor of Computer and Information Sciences at Ohio State University in Columbus, Ohio. He is the author of ``Art of Computer Systems Performance Analysis," which won the 1991 ``Best-Advanced How-to Book, Systems" award from Computer Press Association. His fourth book entitled " High-Performance TCP/IP: Concepts, Issues, and Solutions," was published by Prentice Hall in November 2003. He has recently co-edited "Quality of Service Architectures for Wireless Networks: Performance Metrics and Management," published in April 2010. Further information about Dr. Jain including all his publications can be found at http://www.cse.wustl.edu/~jain/index.html.