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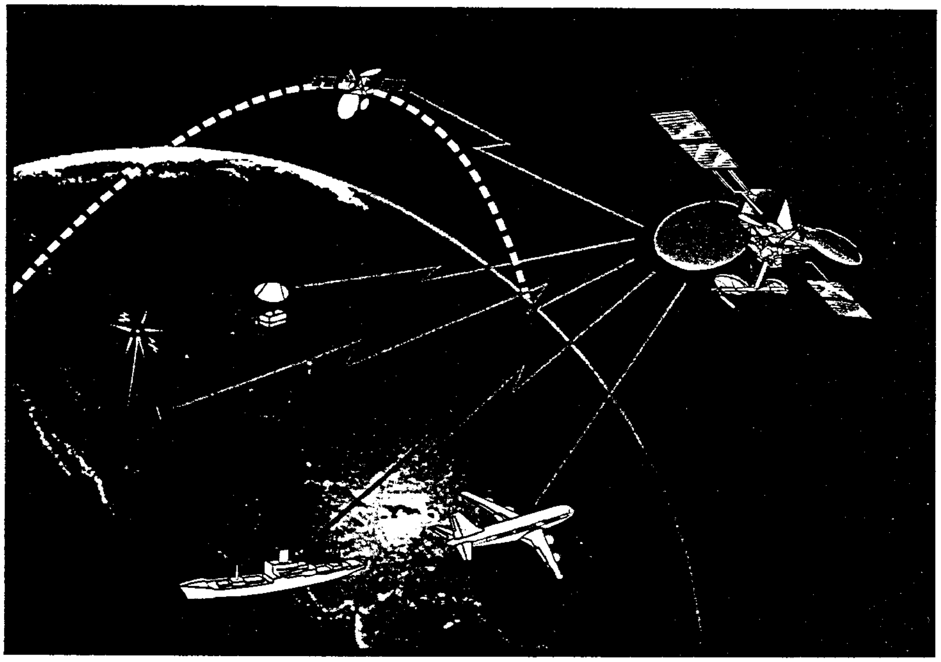
Satellite Networks: Architectures, Applications, and Technologies



August 1998

Center for Satellite and Hybrid Communication Networks

Linking Satellite and Terrestrial Networks for Broadband Internet Services

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NASA Lewis Research Center

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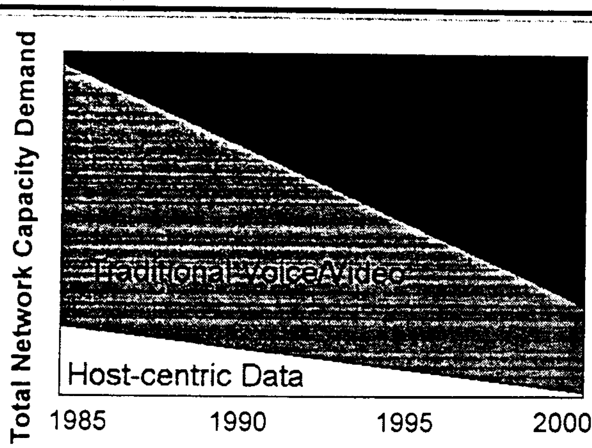
New Business Paradigm



- The "New Data": Internet / Intranet / Extranet applications
  Digital, compressed voice, audio and video

- Paradigm shifts:
  - Data applications require flexible connectivity
  - Applications require much larger capacities and "bandwidth-on-demand"
  - Subscribers require low-cost, high capacity access
  - Enterprise networks require in addition scalability,dependable performance, simple network management, controlled costs

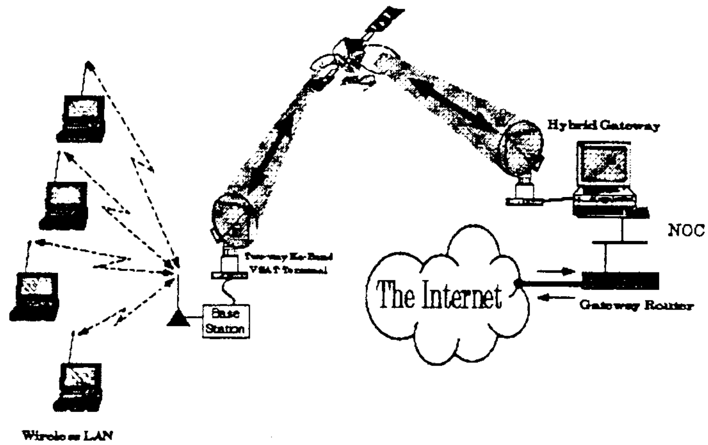
The "Last Mile" is Key

- **Local Access options :**
  - Fiber to anywhere (FTTN, FTTC, FTTH, SDV)
  - Copper twisted pair wire (ADSL, VDSL, ... HDSL)
  - Cable Television (CATV), coaxial cable (HFC)
  - Multichannel Multipoint Distribution Service (MMDS)
  - Local Multipoint Distribution Service (LMDS)
  - Broadband Satellites
- **Not a technology issue**
- **Economic and marketing issue**
- **Time of deployment & market penetration**

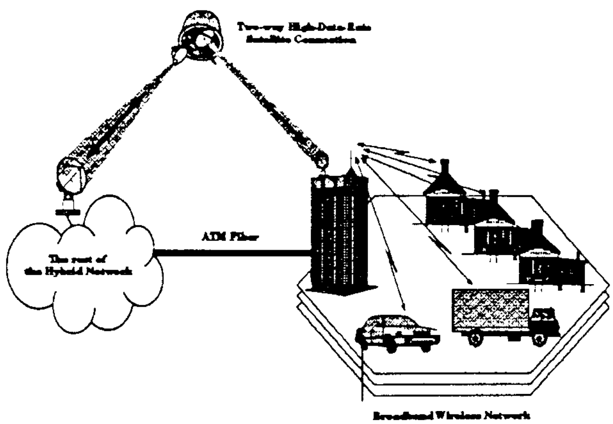
Broadband Wireless Infrastructures: Satellite Constellations

- **DBS major success**
- **New remarkable satellite constellations**
  - FSS or Mobile, LEO or MEO
  - From 8kbps to 1 Gbps and higher; ***on demand***
  - Competition to fiber ("faster than light")
  - On-board processing, spot beams, hoping beams, autonomy
  - Globalstar, Iridium, Teledesic, Spaceway, CyberStar, PanAmSat, Astrolink, ...
  - Newest EHF satellites: Celestri, OrbLink, Lockheed Martin, ...

Hybrid Networks Architectures:
High-Data-Rate Ka-band SatCom and Wireless or Wire-line Terrestrial



Hybrid Networks Architectures:
High-Data-Rate SatCom, Fiber and LMDS



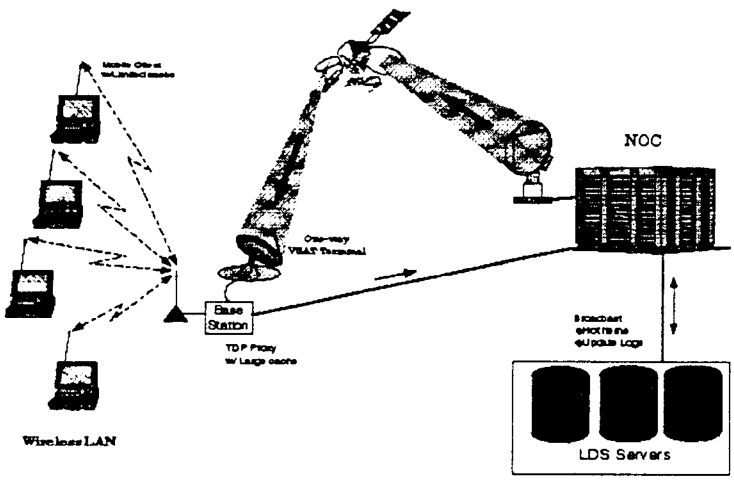
Efficient Broadband Sevices not just a Bandwidth Issue

- Challenge: Exponential growth in demand workloads cannot be met by traditional data services with scalability groth linear in network bandwidth and server capacity
- Traditional unicast (poin-to-point) connection-oriented data services uneconomical and wasteful
- Utilize distributed caching, smart prefetching, dynamic bandwidth allocation, reliable multicast, adaptive hybrid data delivery
- Need to broadacst the right set of data: highly in demand
  - Balance data delivery modes to match user's request
  - Broadcast the right amount of the hottest data and provide the rest on demand

"Push" Information Distribution

- Why important?
  - Audio/video streaming, software distribution, message distribution
  - Give listeners up-to-date -ness guarantee
  - Get network economies of scale and efficiency
  - Event driven enterprises
  - Individualized content need not require per-user data streams: filtering at the desktop, integration at the desktop
- "Push" spending: 1996 $ 8 B, 2002 $ 19 B
- "Push" needs multicast : Intranet and Internet multicast

Distributed Multi-Tier Database Architecture



Network Operations Center (NOC) for Hybrid Internet Service

- **HGW : first NOC object that receives data (Router)**
  - HGW prioritizes Hybrid Internet traffic
- **SGW jobs : mixture of Internet and exogenous traffic**
  - Exogenous traffic: package delivery and data feed traffic
  - SGW maintains four queues : two for package delivery and data feed
    two for the two priority levels of Internet
- **Exogenous traffic high priority : fluctuations in bandwidth allocated to Hybrid Internet**
- **Self-similar traffic: Interactive users as ON-OFF processes**

NOC: Bandwidth Allocation Strategies

- **Comparison of Bandwidth allocation strategies**

Buffer per Connection	500 packets
Total Bandwidth	15 packets/unit time
Number of Connections	5 connections
Constant Arrival Rate	10 packets/unit time
Mean of the Uniform Arrival Rate	5 packets/unit time
Delay Imposed to Queued Packets	0.1 unit time

Common Input Data

Conn1:	1.4469	1.4468	0.0
Conn2:	2.0720	2.0720	0.5298
Conn3:	1.6941	1.6689	0.204
Conn4:	2.0541	2.0524	0.0741
Conn5:	1.7182	1.7088	0.8847
	EB	FB	MDQSF

Average Delays

- All strategies: controller knows (per connection) queue status
- Three strategies investigated:
  - Equal Bandwidth allocation (EB)
  - Fair Bandwidth allocation (FB)
  - Most Delayed Queue Served First Bandwidth allocation (MDQSF
- MDQSF is best

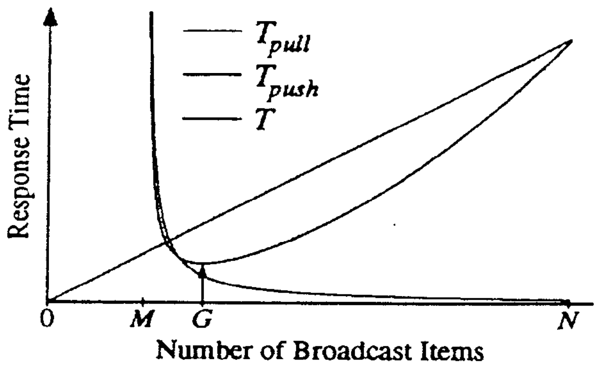
DBS-based Internet Access: IP Multicast and Enhancements

- **Two IETF WGs: TCP over Satellite and Unidirectional Internet routing**
- **Intelligent asymmetric data transmission**
  - **Two types of traffic (depending on threshold T bps):**
    - Low data-rate (or "short length") via terrestrial
    - High data-rate (or "bulky") via satellite
- **Terrestrial LAN extension of DBS-based Internet**
  - Distribute DBS services from a single receiver out to multiple users, thus reducing cost
  - Satellite hybrid hosts can redistribute data to mobile users
  - "Local loop" anything: Ethernet, ATM, cable TV, wireless

Hybrid Data Delivery

- **Objective: deliver needed data with minimum delay to very large numbers of users**
- **Pure data broadcast ("push"):**
  - Passive users; Accessed concurrently by any number of users
  - Limitation: users wait for data of interest to appear
  - Access latency depends on volume of broadcast data
- **Pure unicast ("pull"):**
  - Active users; Cannot scale beyond capacity of server and network
  - Access latency depends on aggregate workload and network load
- Ammar and Wong (1985), Wong (1988); teletext, videotex
  Gifford (1985, 1990); community information services (Boston)
  Imielinski and Badrinath (1994), Franklin and Zdonik (1996); wireless communications and mobile computing

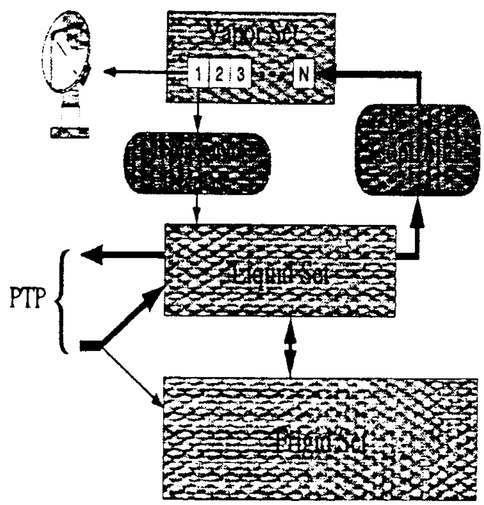
Hybrid Data Delivery Model



- DB contains N items of equal size S
- Demand for i^{th} item : Poisson ; rate λ_i
  $\lambda_1 > \lambda_2 > \ldots > \lambda_N$
- Server M/M/1; mean service time = $1/\mu$
- Server can broadcast at rate B

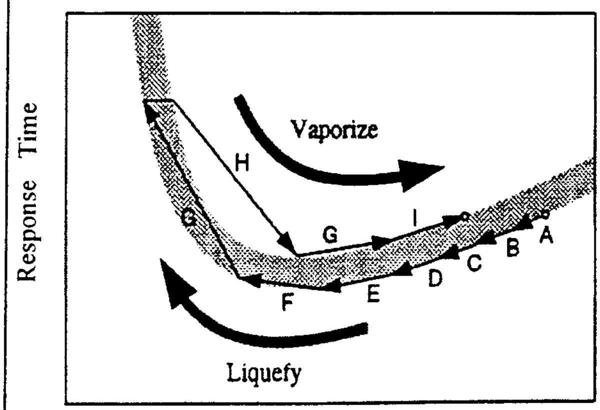
- Broadcast n first items ; On-demand N-n items; $\Lambda_k = \Sigma_1^k \lambda_i$
- Expected response time for requests : $T_{pull} = 1/(\mu - (\Lambda_N - \Lambda_n))$; $T_{push} = nS/2B$
- Expected response time for hybrid : weighted average of T_{pull} and T_{push}

Adaptive Repetitive Data Broadcast



- Size and content of broadcast continuously updated; Not fixed schedule
- Queue storing vapor data: *V*
- Item broadcast appended to tail of *V* and its temperature reduced by Cooling Factor
- Contents of *V* modified every cycle defined by a placeholder
- Notification on to-be broadcast items by broadcasting index: *the signature of V*

Two-Phase Algorithm to Update Broadcast Queue Contents



A_V

$\lambda_A \le \lambda_B \le \lambda_C \le \lambda_D \le \lambda_E \le \lambda_F \le \lambda_I \le \lambda_G \le \lambda_H$

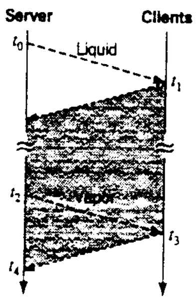
Vapor : A, B, C, D, E, F, G ; Liquid: H, I

- Sort items by their temperature
- Demote to liquid all vapor data with temperature < hottest liquid item
- Marginal gains :

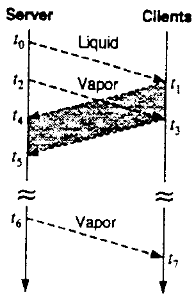
(2a) Demote vapor items in increasing order of temperat. while $\theta > \theta_0$

(2b) Promote liquid items in decreasing order of temperat. while $\theta < \theta_0$

Temperature Probing



Without probing



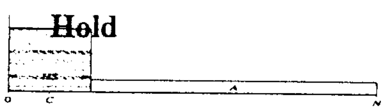
With probing

- Critical factor: probing interval $[t_0, t_2]$
- Probing time = <u>*Probing Factor*</u> $x\ (N_V / \Lambda_V)$

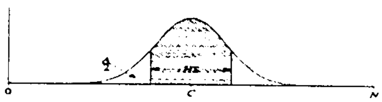
- **Avoid premature demotion of a very hot item**
- **Temperature probing :**
  - **After demotion at t_0**
  - **Re-promote at time t_2**
  - **Creates small window for re-evaluation: probe the temperature of the item**

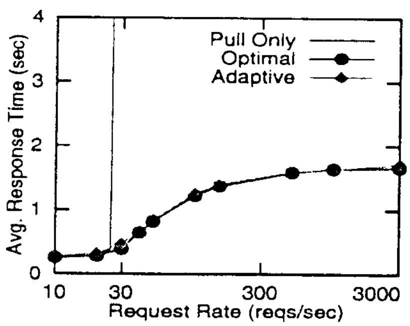
Performance Evaluation: Static Workloads

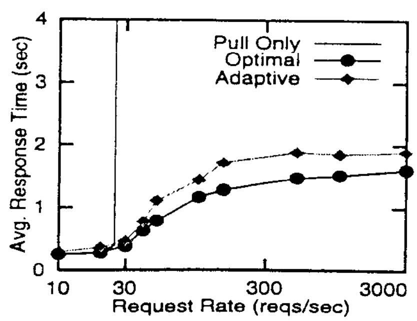
Hold-Cold Uniform



Gaussian







Performance Evaluation: Simulation Experiments

- **Parameters:**
  - Broadcast and down link rates: 12 Mbps
  - Uplink rate: 28.8 kbps
  - DB has 10,000 items, each 50 kB in size
  - System's pull capacity μ : 30 items/sec
  - Vary workload from light ($RR < \mu$) to heavy ($RR = 100\,\mu$)
- **Response time depends only on hot-spot size (100 items) (not on workload intensity**
- **Scalability increased by two orders of magnitude**

Acknowledgements

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- **For additional related papers/reports see: http://www.isr.umd.edu/CSHCN**