Evaluation Method

- Interim and Final Report
- Attendance is not Checked, but, ...
- Questions or Comments are Mandated
  - In the quater, questions or comments with technical content must be made at least twice during lecture (may be in Japanese)
  - Good questions and comments will be awarded with points
  - Declare your name and student ID after each lecture, if you make questions or comments

Advanced Lecture on Internet Infrastructure

2. Physical Layer of the Internet

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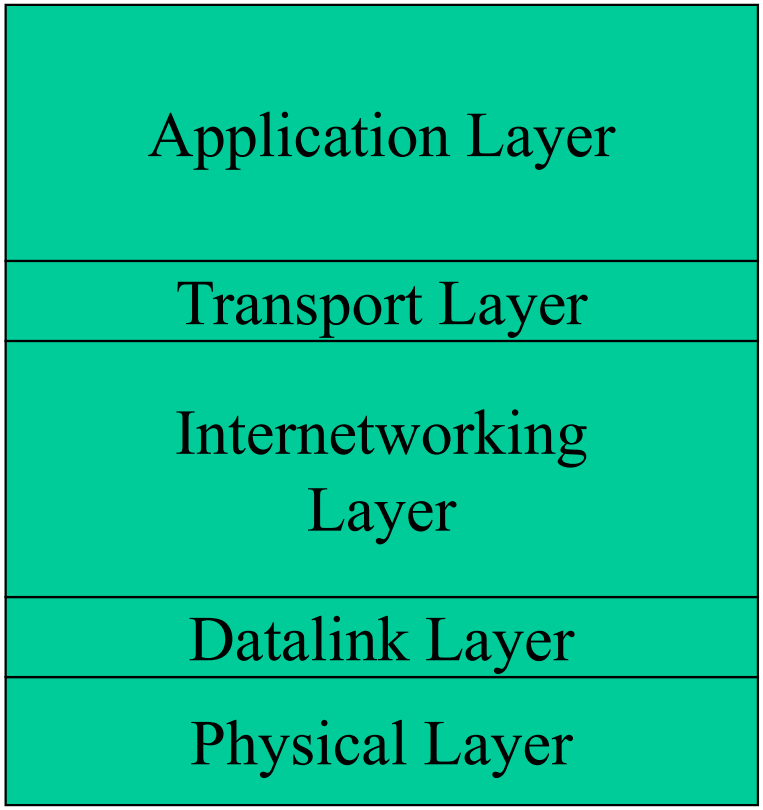
ftp://chacha.hpcl.titech.ac.jp/infra2.ppt

Physical Layer

- Layer to Correspond (Far Reaching) Physical Phenomena and Information
  - Electricity (directly handled by semiconductors)
    - processing is easy
  - Light (propagate straightly, no interference)
    - must for long distance and/or high speed transmission
  - Radio Waves (propagate in space, may go around obstacles)

Layering of the Internet

- Physical and Application Layers are Essential
- The Internetworking Layer does as Much Things as Possible
- Datalink and Transport Layers should Avoid to do Thing



Here is the Essence of the Internet

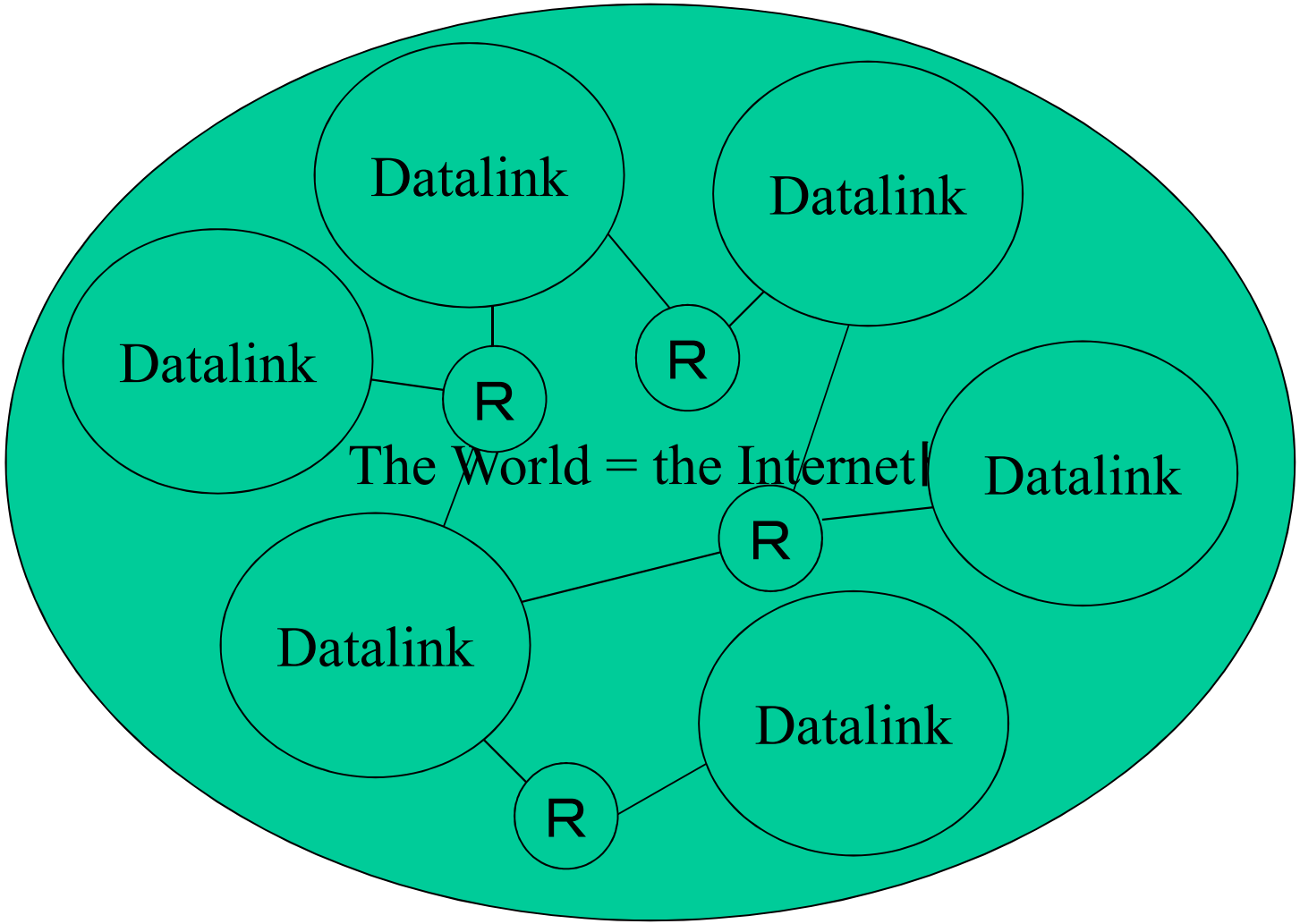
Layering Structure of the Internet

CATENET Model

- Connect Small Datalinks by Routers
  - Broadcast is meaningful within each datalink
    - Can communicate without various configuration
  - What is small is # of devices
    - may be large geographically

CATENET Model

- CATENET Model
  - Many small (w.r.t. # of devices) datalinks interconnected by IP (Internet Protocol) routers



R : Router

CATENET Model

Classification of the Internet

- Backbone
  - Connect between Internet Stations
  - Ultrafast (10Gbps~∞)
- Access Network
  - Connect between a home and an Internet station
  - moderately high speed (several Mbps~∞)
- Most money is expensed on access network

Last Mile Problem (of Access Network)

- Most Expense on Installation
- Distance between Tokyo & Osaka <1000km
- Typical distance between stations and subscribers is about 5km
  - if a station is connected to 40k subscribers
    - using 200 cables each containing 200 cores, total cable length is 1000km
  - if drop line from the cable is 25m long
    - total drop line length is 1000km
    - radio wave? what equipment? power?

Examples of Physical Layer

- Point to Point Media
  - Carry information (bit, symbol) stream
  - or packet stream (pigeons etc.)
- Broadcast Media
  - Wireless LAN (access network)
  - Satellite Communication (Wide area (backbone+access))
  - Point to point media combined by repeaters

WDM Transmission (Backbone)

- Capacity of optical fiber > 1Tbps
- 10Gbps transport by electricity is hard
  - at 10Gbps, with 32 parallel lines, each line needs 300Mbps
    - approaching limitation for inter-chip distance
- 100 lights modulated at 10Gbps may be sent in parallel
  - multiplexing lights by wavelengths is easy
    - Wavelength Division Multiplexing

Economy of Backbone

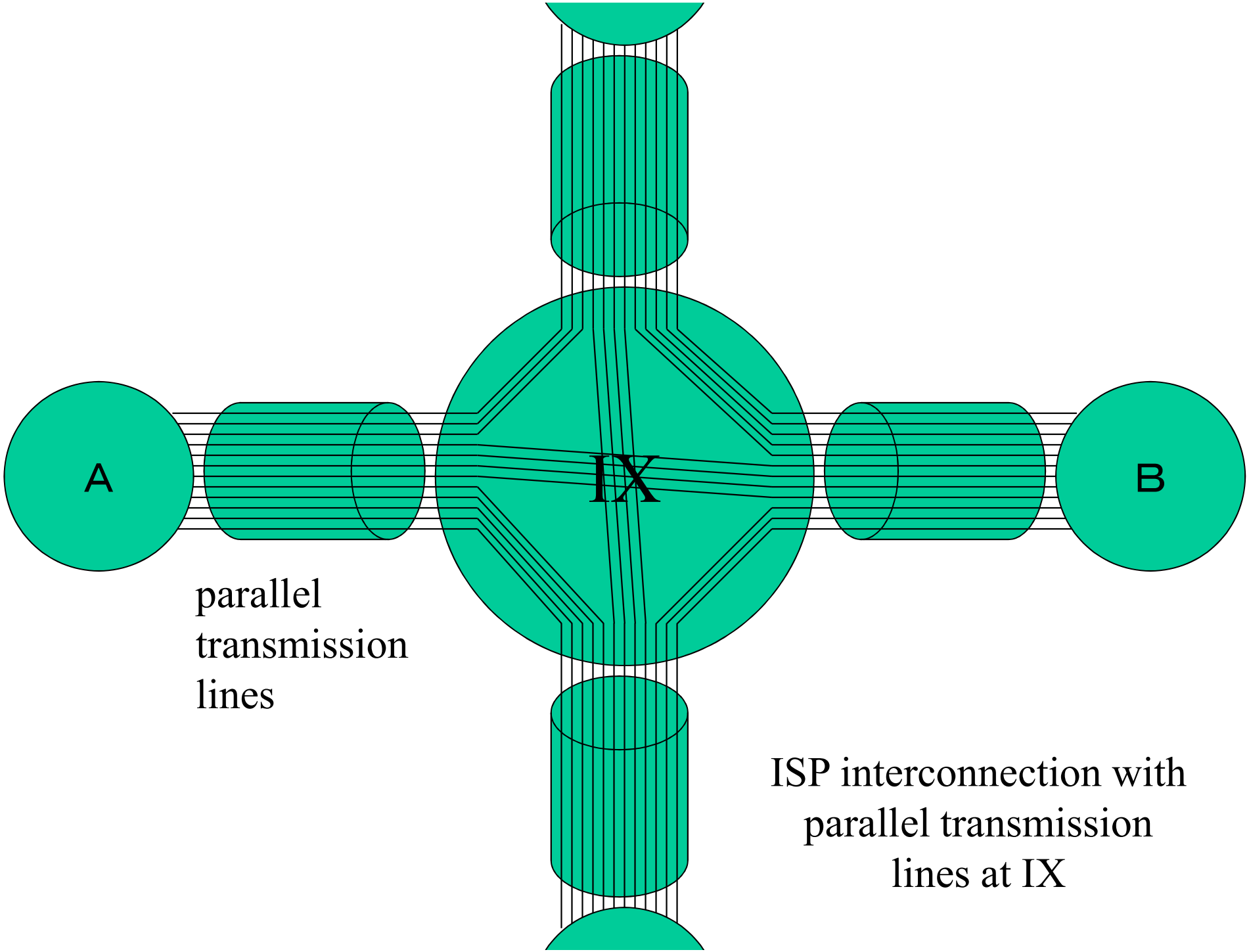
- Most Expense is for Installation and Relays
  - Optical fiber is the best with long relay span and ultra high speed
  - Cost of cable itself is negligible regardless of the number of fibers 1 or 1000
    - cost of a fiber is cheap if a cable with many fibers in
- Relay Cost is Proportional to the Number of Fibers
  - WDM with optical amplifiers saves cost
    - unless WDM equipments cost a lot

Backbone Routers

- high speed routers are necessary
  - price is roughly proportional to speed (massibely parallel router)
  - not all subscribers needs highest speed
    - slower than sum of speed of access routers is fine
- long distance communication
  - direct fiber link is better
- optical router with many eavelength packets
  - can operate at 1Tbps or faster

Rouging by physical layer?

- if there are many parallel transmission lines
  - Connection between lines may be switched
- destination is (mostly) fixed
  - packet-wise switching is impossible
    - not really rouging (routing necessary somewhere)
- switch speed is that of physical layer
- though wave length routing (?) is popular
  - applicable to any parallel transmission lines (e.g. fibers in a cable)



ISP interconnection with
parallel transmission
lines at IX

Access network for the Internet

- dial-up Internet connection
  - connect to the Internet through phone network
  - physical and datalink layers are phone network
  - connect when information is necessary
- persistent connectivity to the Internet
  - physical layer dedicated to the Internet
  - obvious when phone network disappears
  - can always offer information

Phone Business & High Speed Network

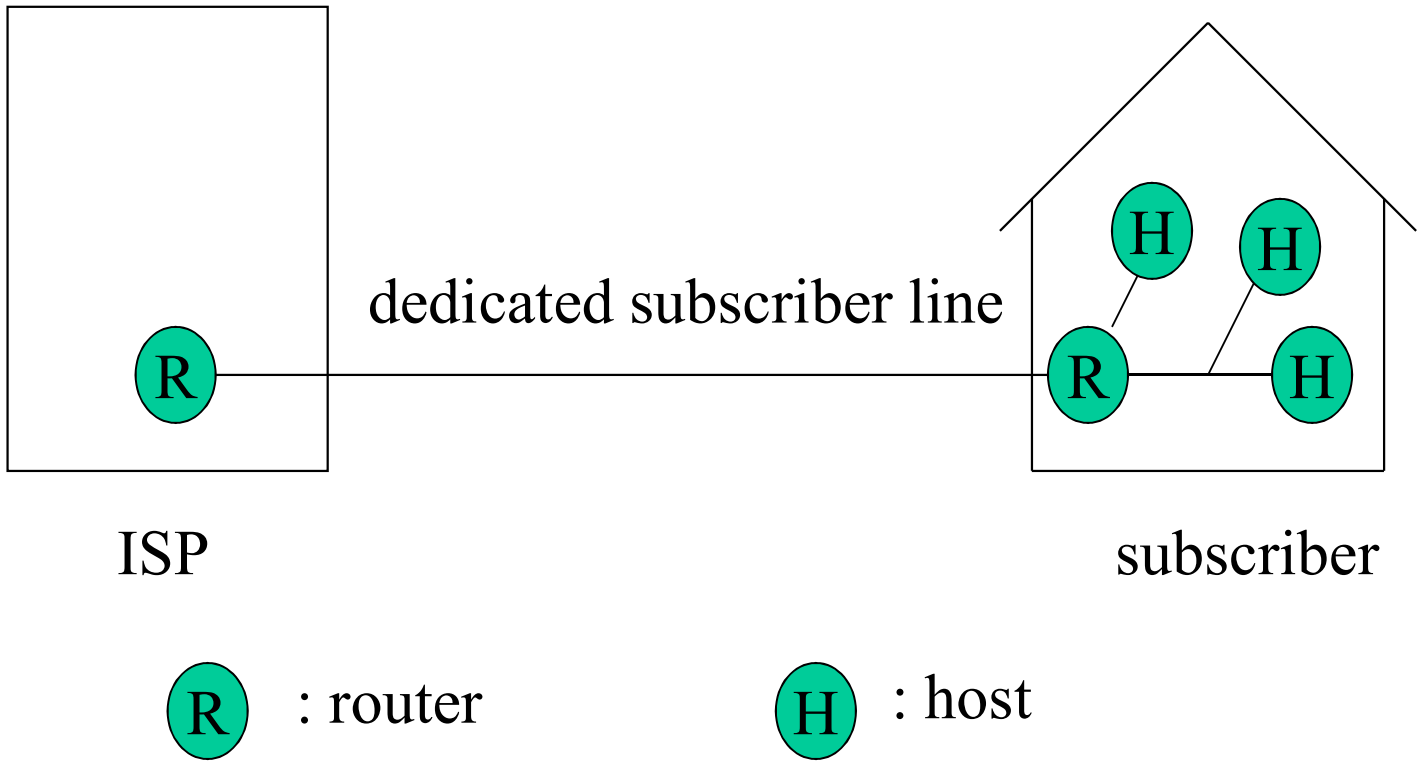
- phone network is
  - to transfer voice
- phone network business is
  - to charge ￥10/3min at 64kbps local call
- high speed network as phone network business
  - ￥15000/3min at 100Mbps local call
  - customers can’t afford even with 1/10 discount
    - high speed network is unnecessary

Internet Business & High Speed Network

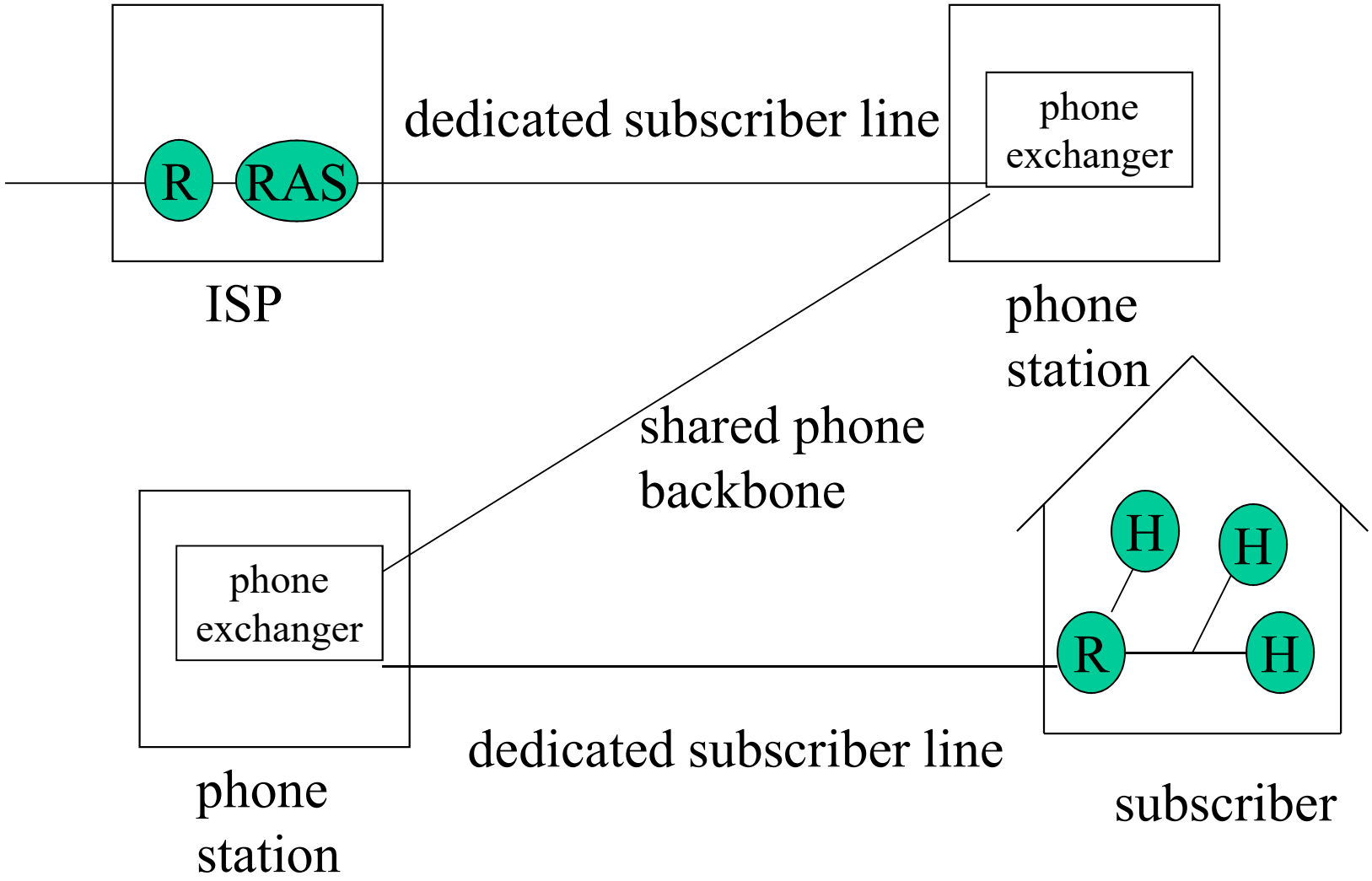
- Internet is
  - to connect computers, originally
    - usable even if slow, though faster is better
- Internet business is
  - to collect fair amount of money ($50/m?)
  - use the most inexpensive and high speed devices at that time
- Internet business and high speed network
  - 100Mbps~10Gbps with FTTH

Ideal Access Network Once Considered by Phone Companies

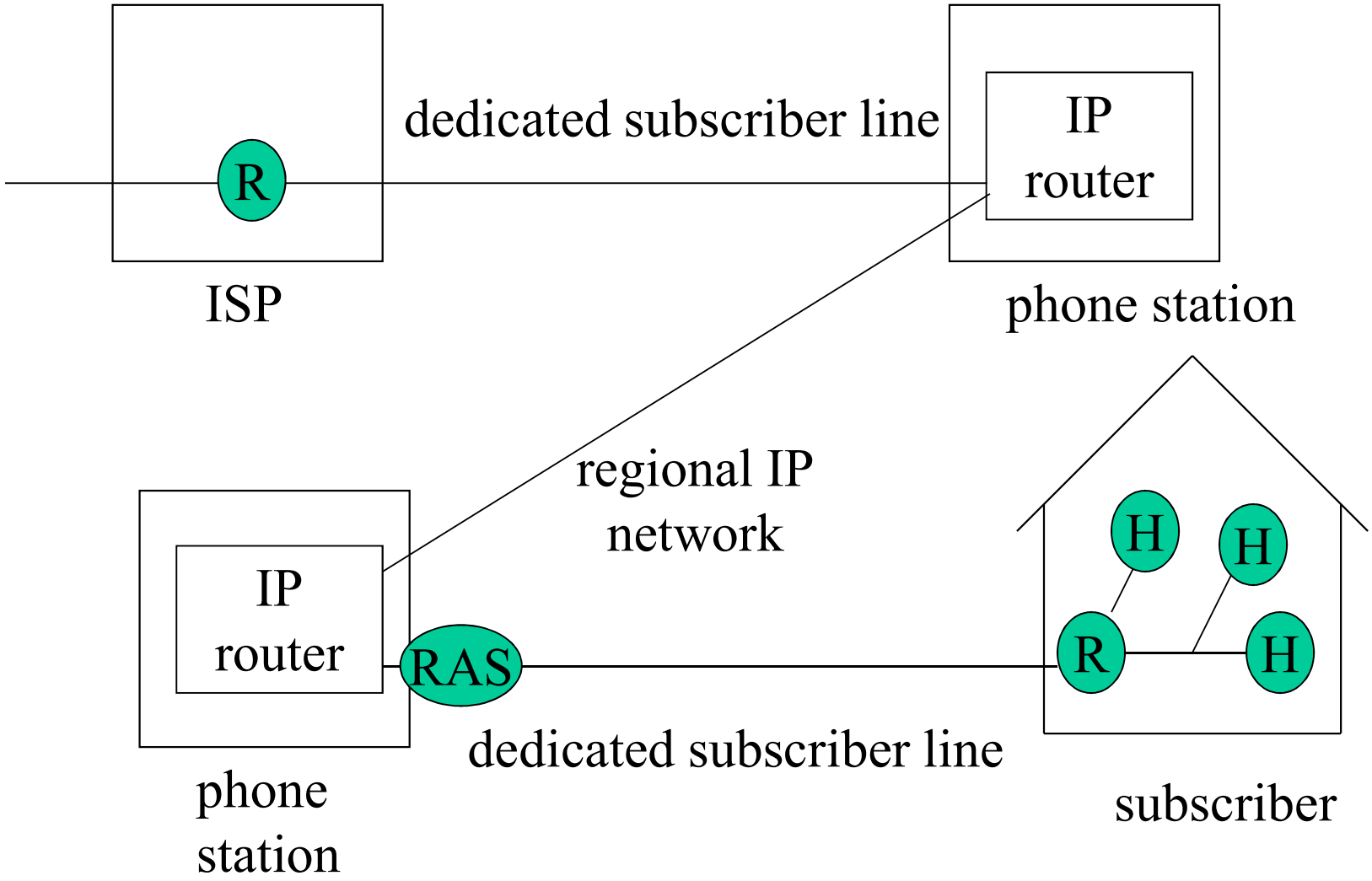
- digitize access network by ISDN
  - 64kbps is a lot more than enough for voice and 2*64kbps is enough for future demand
- make access network faster with B-ISDN
  - 156Mbps should be enough for any application
  - share expensive fiber and devices
    - PON (Passive Optical Network)
- Price? (￥10/3min @ 64kbps local call)



proper Internet connection



distorted Internet connection 1



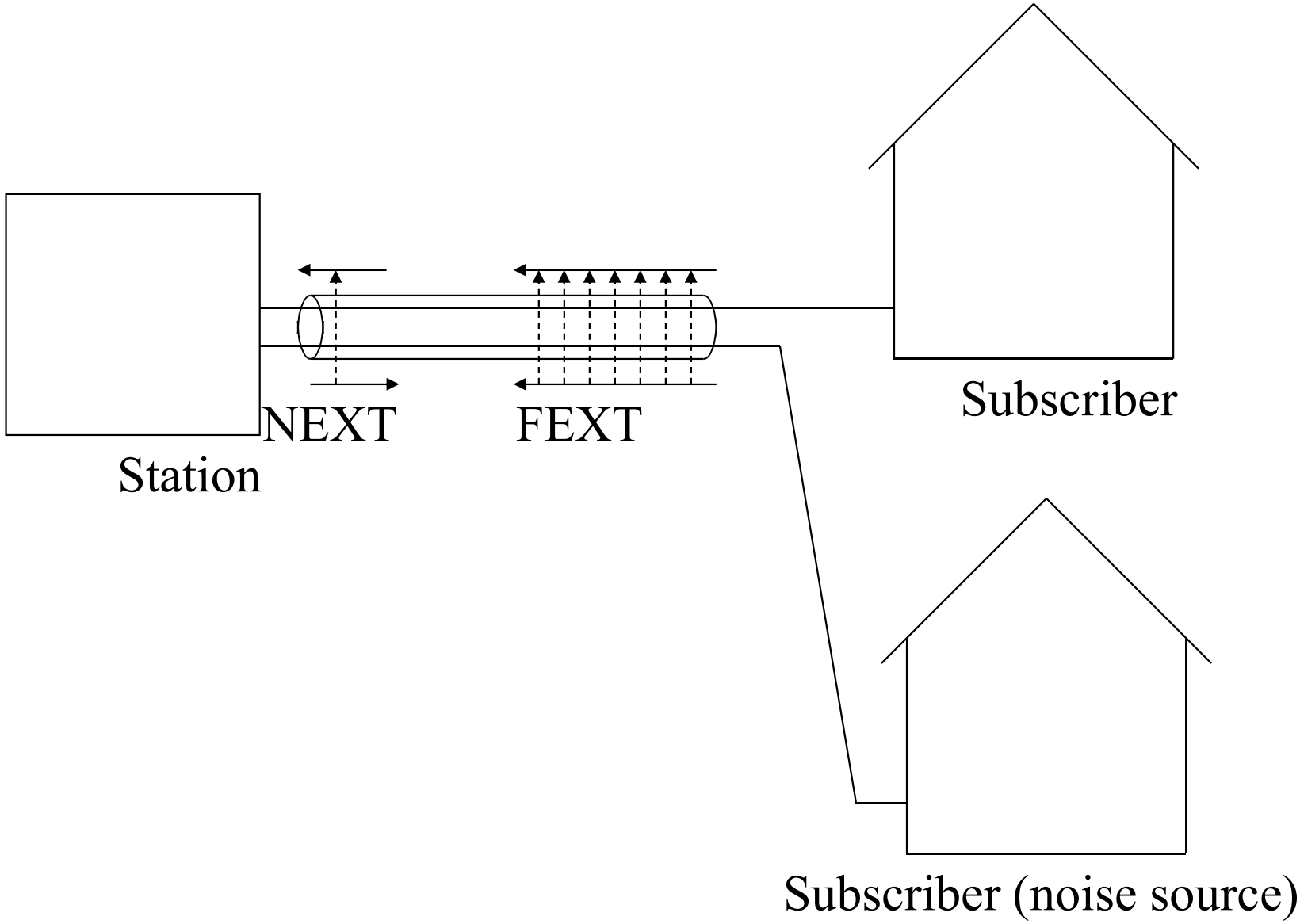
distorted Internet connection 2

Not-ultra Fast Internet Connection

- ADSL
  - physical layer is twisted pair for phone network
  - several Mbps, at most?
- Cable Internet
  - physical layer is COAX for CATV
  - several tens of Mbps shared by many
- a lot better than ISDN

ADSL

- use cupper line between phone station and home
  - capacity of cupper line is extracted up to theoretical limit by advanced signal processing
    - capacity of cupper line is determined by frequency and S/N (Shannon)
      - ADSL use 1MHz bandwidth for 10Mbps or so
- primary cause of noise is cross talk (XT)
  - near end XT is severer than far end XT
  - XT between ADSL can be avoided



Far end XT (FEXT) and near end XT (NEXT)

Problems of ADSL

- not very high speed (usually several Mbps)
  - of course, as it is cupper line for voice
- Asymmetric BW (want downstream video)
  - not good to offer information from home
- Japanese-style ISDN is the worst noise source
  - 4 times more BW than ISDN in other countries
  - step shaped signal
  - # of subscribers decreased, fortunately

ADSL and PSD (Power Spectrum Density) standard

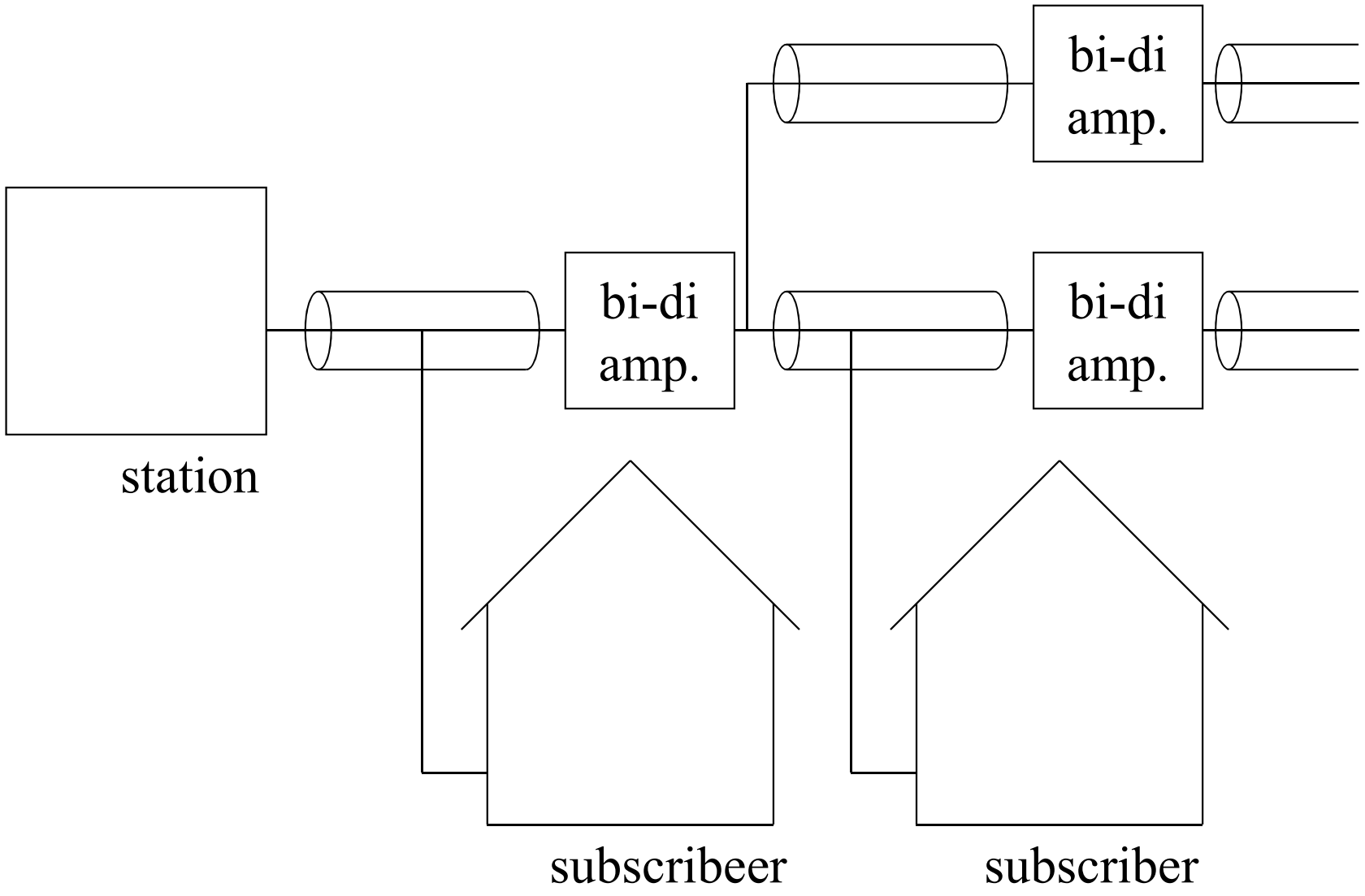
- as ADSL use high frequency, compatibility with others is a problem
  - coordination between operators necessary
- in usual contries
  - coordination between ADSL and other technologies
- in Japan
  - struggle between ADSL operators makes situations complicated

VDSL (High Speed ADSL)

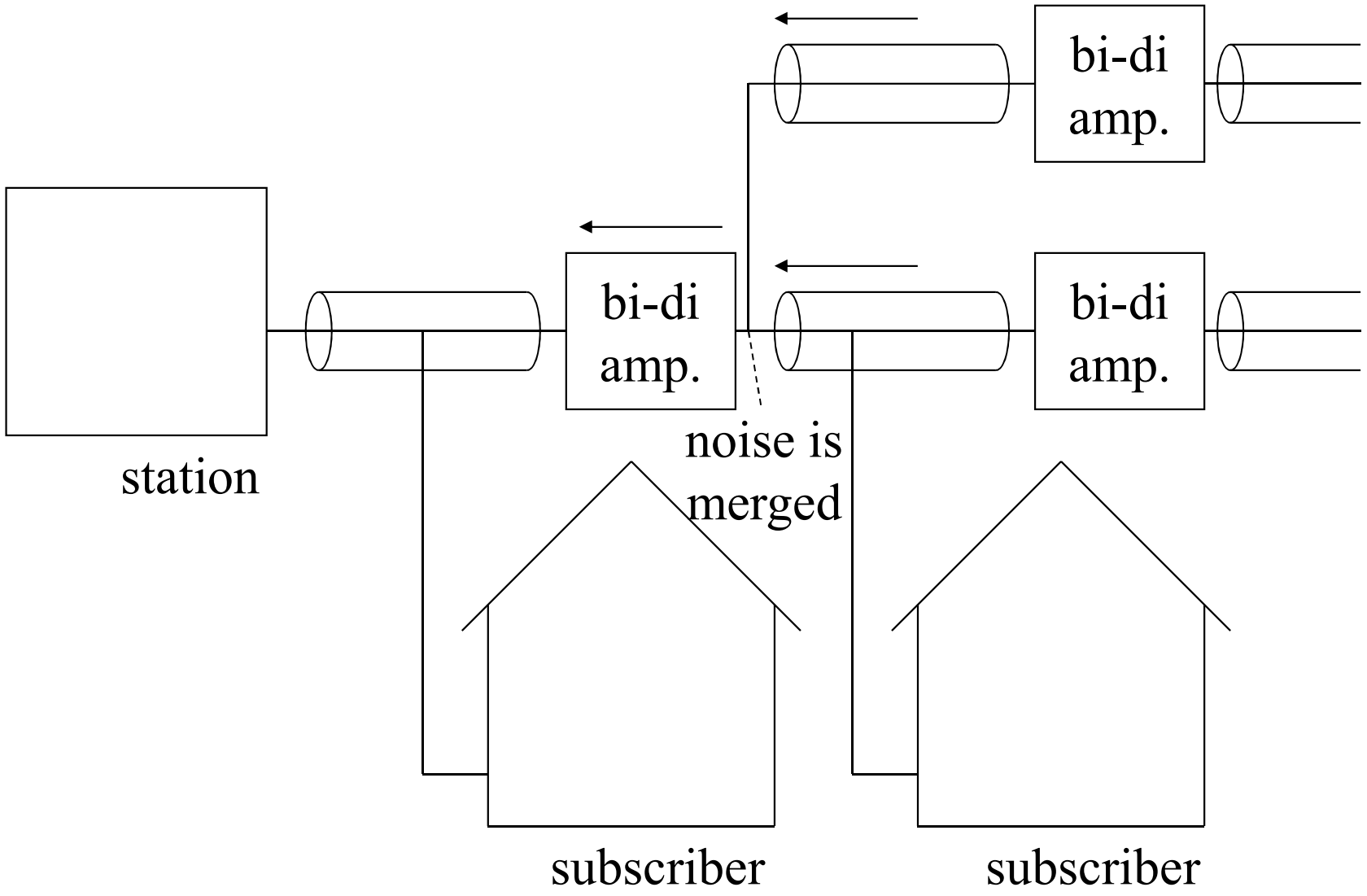
- use same frequency up and down stream
  - down stream speed improves
  - up stream speed disimproved a little
- use higher frequency upto 2(4) MHz
  - can be 25(50)Mbps, if distance is short
  - 100Mbps? maybe
- But, only if distance is short
  - not competitive if active relays are placed on electric poles

Cable Modem

- use COAX cable between CATV station and home
  - capacity of COAX cable is extracted up to theoretical limit by advanced signal processing
    - 18~36Mbps for each TV channel (6MHz)
  - a TV channel is shared by many (1000?)
- upstream communication has difficulty
  - ingress noise
  - timing coordination



cable modem internet



cable modem internet and ingress noise

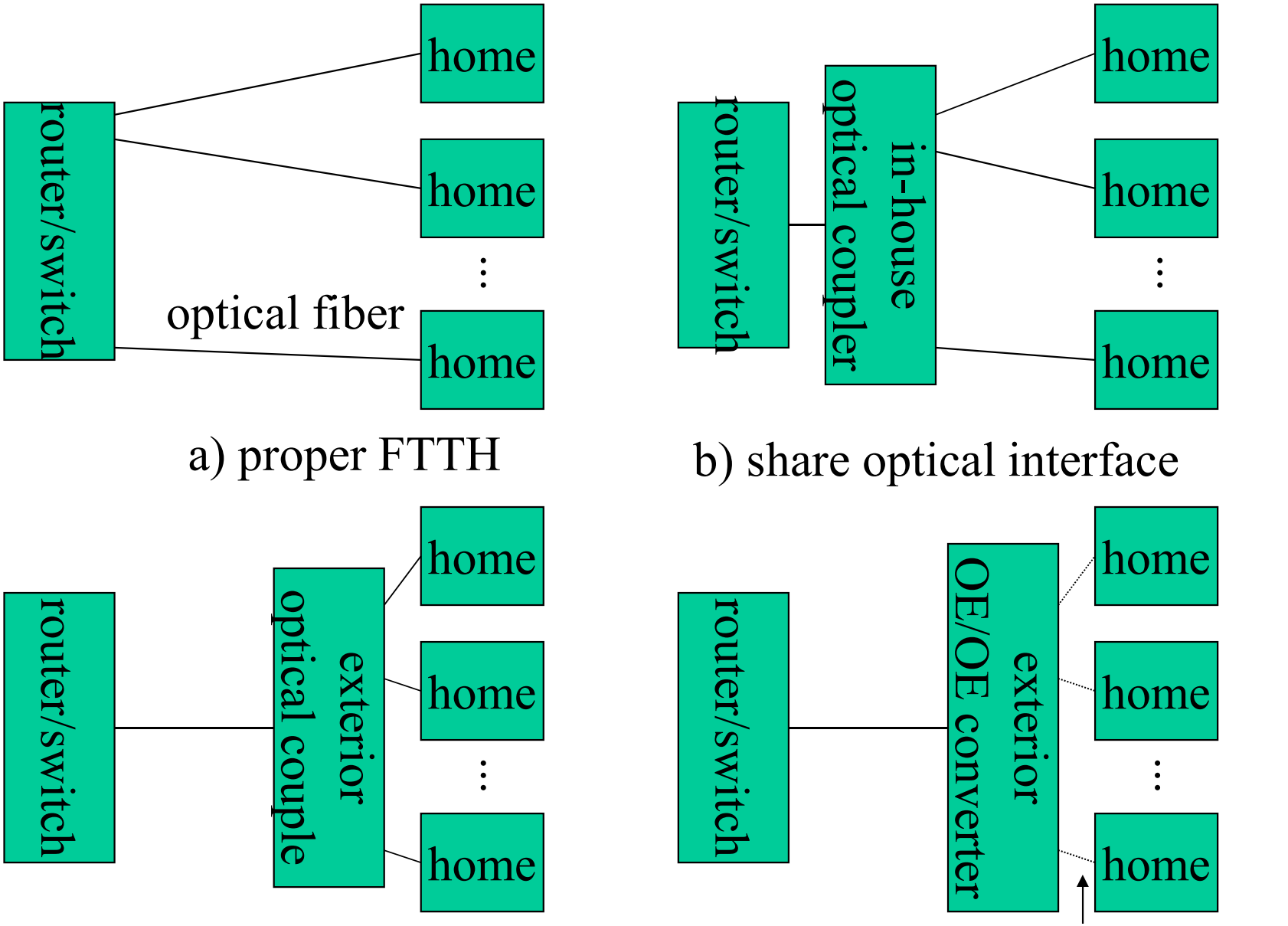
FTTN (Fiber To The Home)

- optical fiber to every home
- just simply
  - directly connect home and station devices by fiber
  - 100Mbps optical Ethernet is cheap
- phone companies makes it complicated
  - PON, GPON and GEPON by optical repeaters

  リピータでPON、GPON（Gigabit　PON）
    - G(E)PON share 600M(1G)bps by 32 subscribers

Combining point-to-point media by repeaters

- not difficult
- bandwidth is wasted
  - everyone receives same signal
- bandwidth of devices is also wasted
  - devices operate at speed of media
- make datalink layer complicated
- no need if L2/3 devices inexpensive



forms of FTTH／FTTC

Economics of Access Network

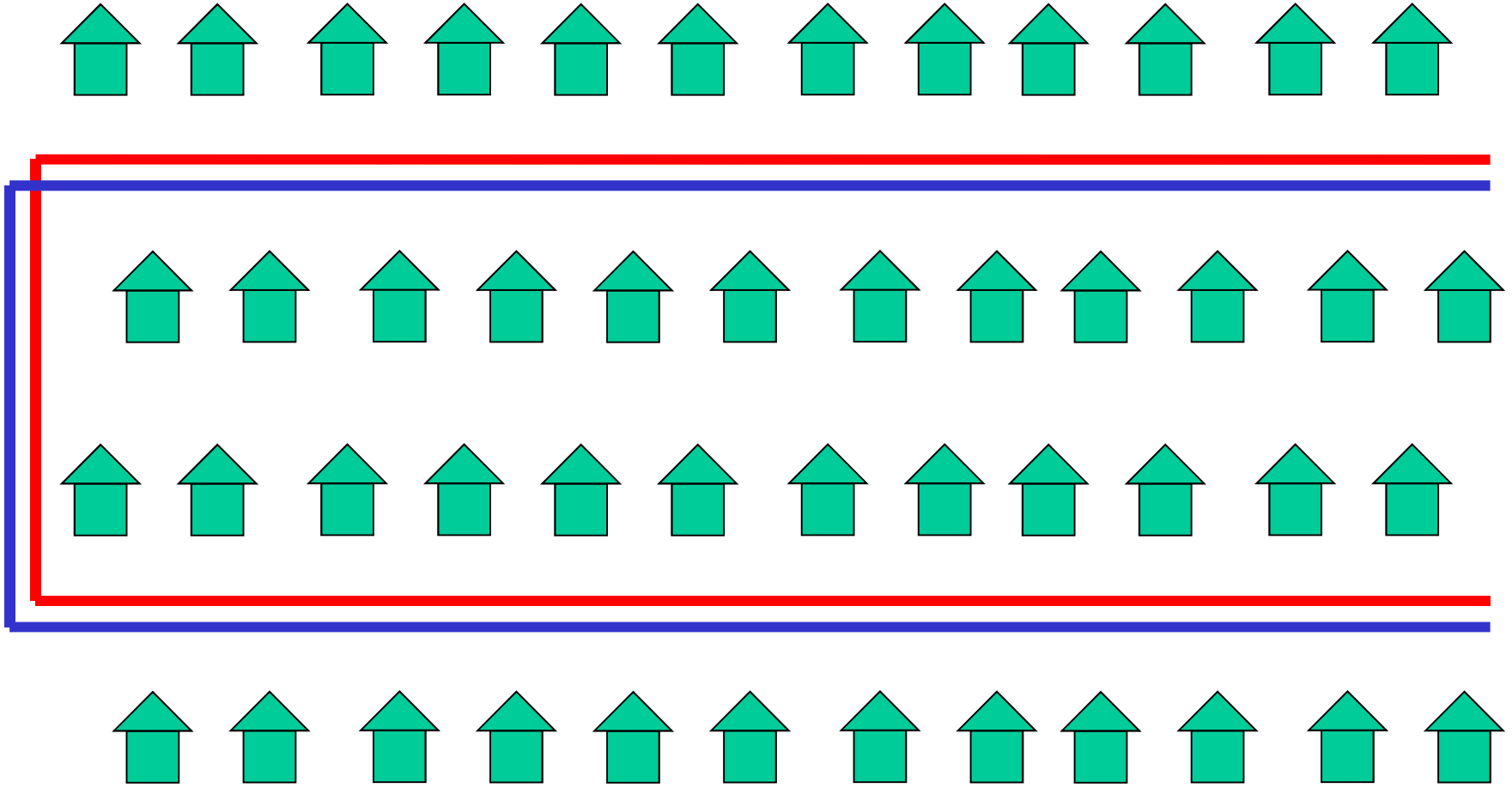
- most expense is for cable installation
  - $50/m*4km/(200 subscribers~$1000
- regardless of cable time (cuppoer, COAX, 1 fiber cable, 1000 fiber cable) cost of cable is negligible compared to installation cost
  - $1000~$2000 for each home
    - about $10/month for 20 years
- Should install 1000 fiber cable only!

Natural Regional Monopoly of Intrastructure Business

- infrastructure business with regional access network to each home natually monopolized
  - if two companies have separate access networks
    - cost of the network is same, revenue prop. to share
      - company with smaller share will lose, no new comer
  - communication, power grid, water, postal, railway etc.
- privatization of business with natural regional monopoly is unquestionably wrong
  - needing regulatory power for price control and universal service leading to amakudari
    - public service is better

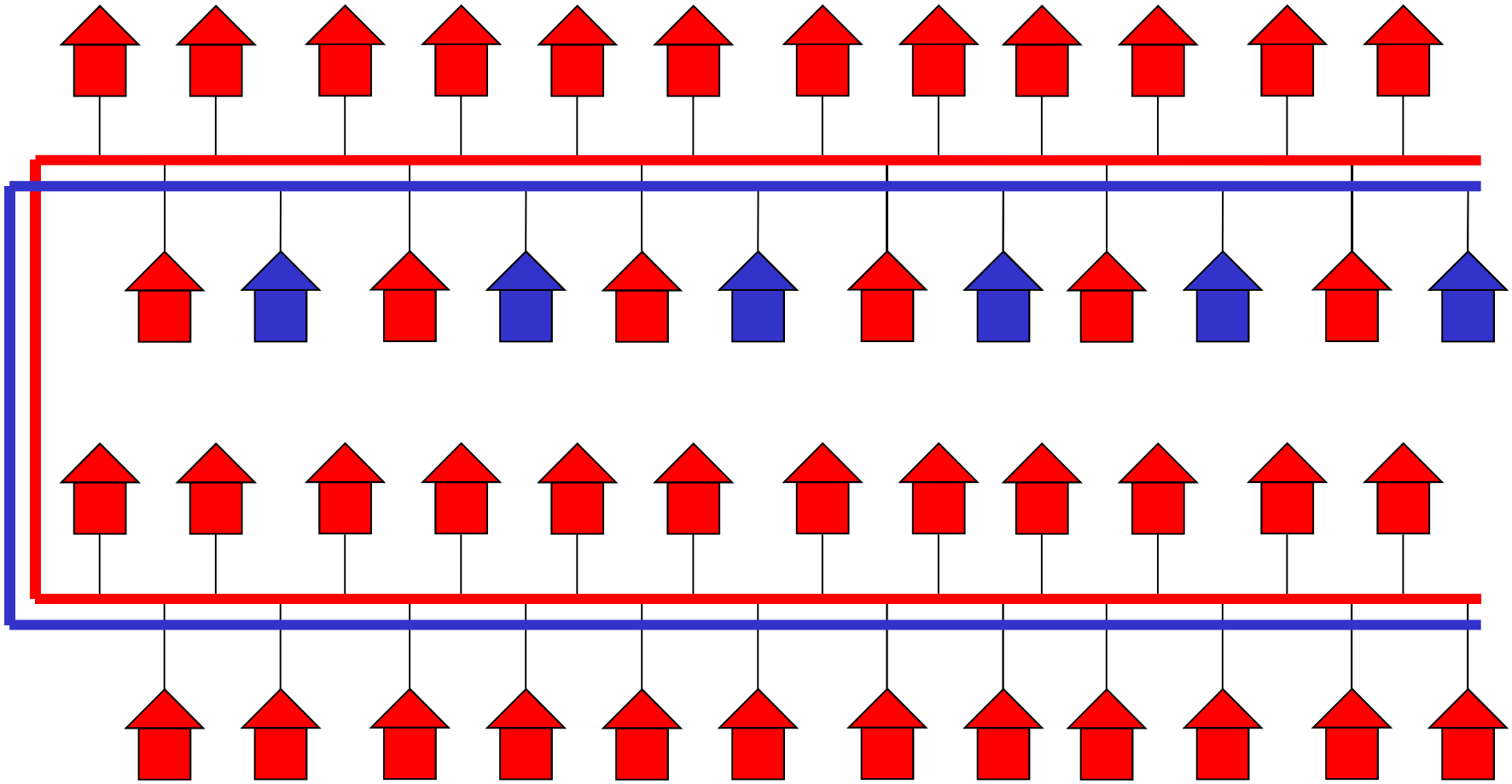
Access Network with 1 Company Monopoly

Two Competitive Companies (cost for each company is same)



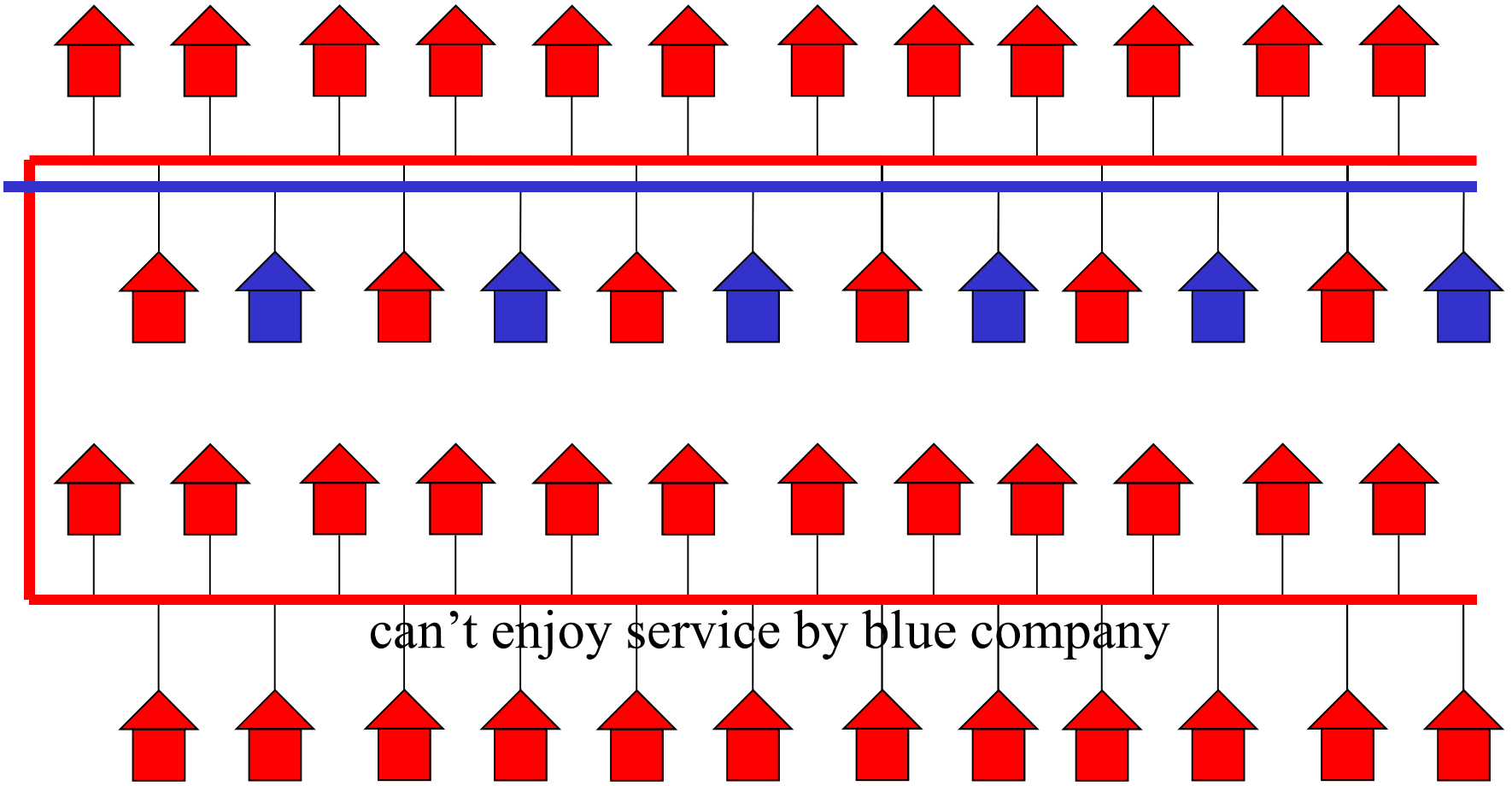
Two Competitive Companies

(revenue proportional to # of subscribers leading to natural monopoly)



Two Competitive Companies

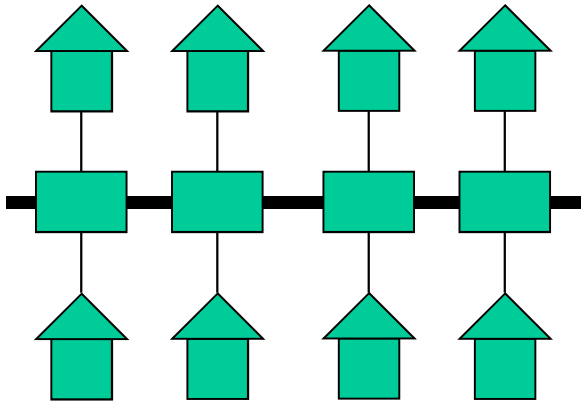
(save infrastructure only to loss possible subscribers)



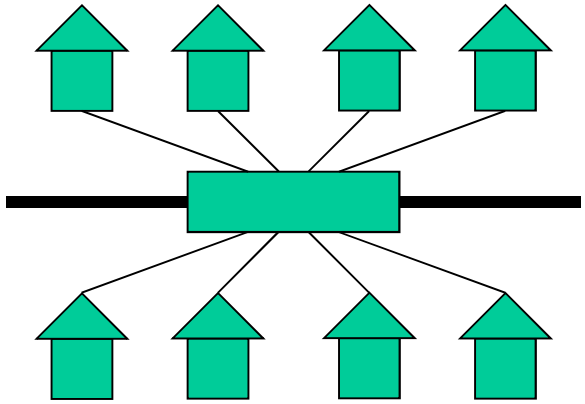
Fiber Provisioning by NTT

- One cable with 1000(0) fibers from station
  - cable branches off midway
- to each feeder point (1000 subscribers), only 20~40 (finally 200) fibers reach
  - even though cost is mostly same for 1000 fibers at the feeder point
- Must share 1Gbps by 32 home for long time
  - GEPON (phantom of B-ISDN)

Is PON Inexpensive?



Single Star



Passive Optical Network

(passive double start)

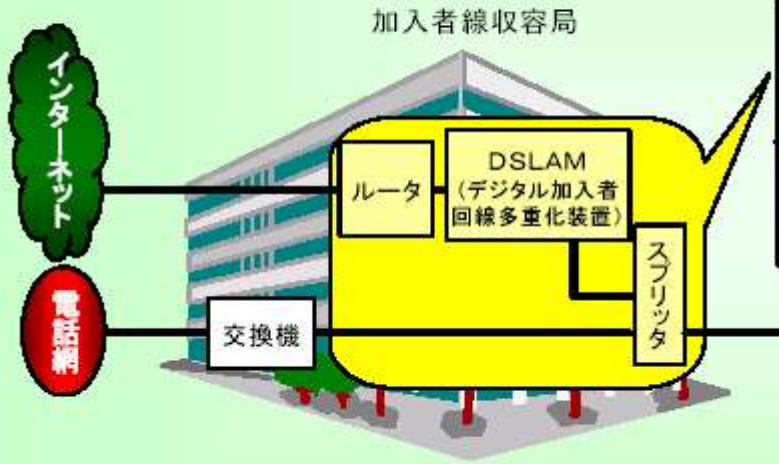
Last Mile Problem

- most expense is for cable installation
- distance between Tokyo and Osaka < 1000km
- distance between station and subscriber ~ 5km
  - assume 40000 subscribers for each station
    - 200 200 fiber cables (total distance 1000km)
- if drop cable from trunk cable to home is 25m
  - total drop cable length for 40000 subscribers is 1000km
  - PON with sparsely distributed subscribers needs even more lengthy drop cables

各ブロードバンドの整備コスト事例

FTTH（PON方式、SS方式）、ADSL及び無線（FWA）について具体的な整備事例をもとに提示。なお、設備構成、世帯分布の状況、地形、局舎の状況等の諸条件によりコストは変動するので、あくまで例示として提示する。

ADSLコスト事例（1収容局、500世帯対象の場合）

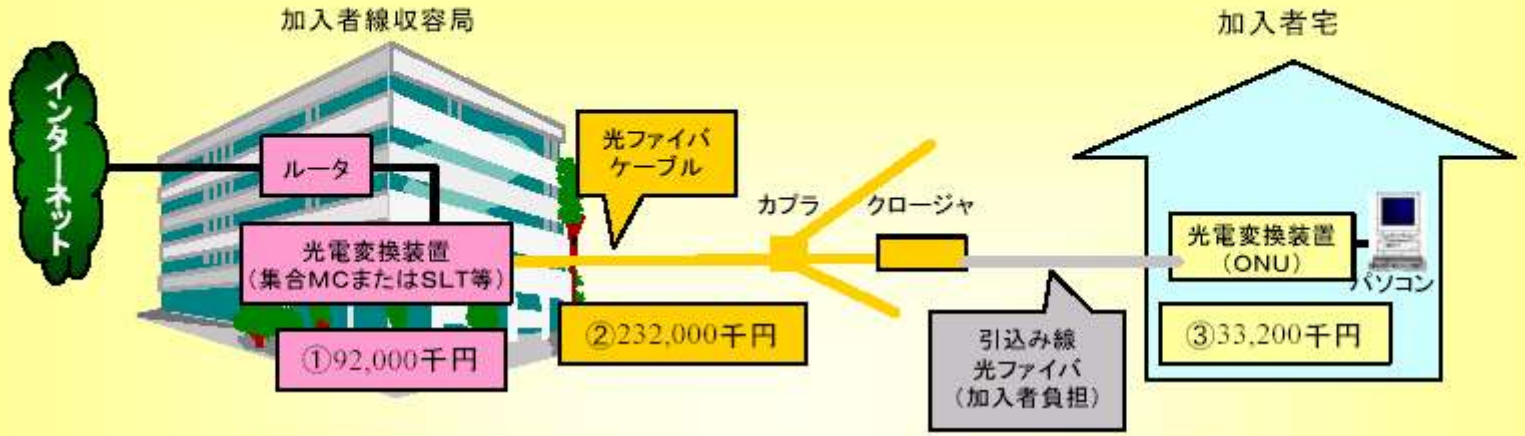


DSLAM等	約5,000千円
ネットワーク装置	約5,000千円
NTT回線切り替え費用	約1,500千円
合計 （1世帯あたり整備コスト）	約11,500千円 （約23千円）

※局舎改修費は除く。

http://www.soumu.go.jp/main_sosiki/joho_tsusin/policyreports/chousa/bb_seibi/pdf/041209_2_14.pdf

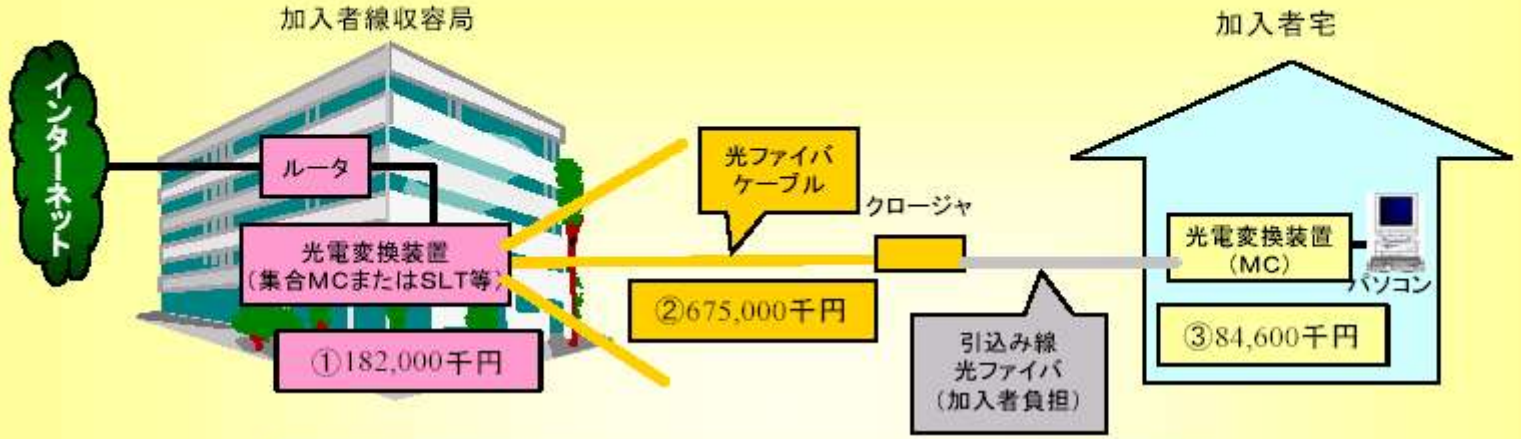
FTTHコスト事例①（整備対象世帯数：1,150世帯、PON方式の場合）



①センター装置（SLT、ルータ等）	約92,000千円
②光ファイバ（工事費、材料費等） ※ケーブル長：51km、最大芯線：192芯	約232,000千円
③宅内装置 ※1,150台	約33,200千円
合計 （1世帯あたり整備コスト）	約357,200千円 （約311千円）

○　人口約4,000人の自治体。（世帯密度は28.8世帯／k㎡）

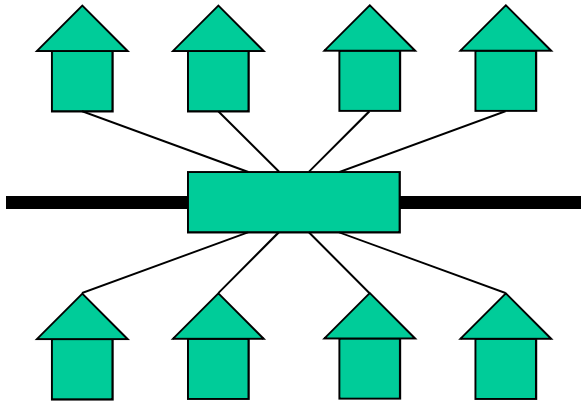
FTTHコスト事例②（整備対象世帯数：3,100世帯、SS方式の場合）



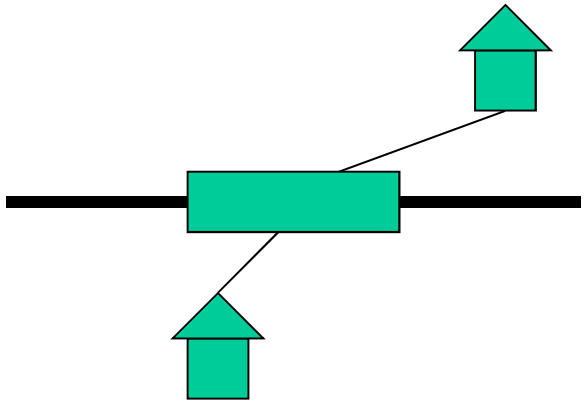
①センター装置（集合MC、ルータ等）	約182,000千円
②光ファイバ（工事費、材料費等） ※ケーブル長：221km、最大芯線：1,664芯	約675,000千円
③宅内装置 ※3,100台	約84,600千円
合計 （1世帯あたり整備コスト）	約941,600千円 （約304千円）

○　人口約11,000人の自治体。（世帯密度は16.2世帯／k㎡）

PON disables competition



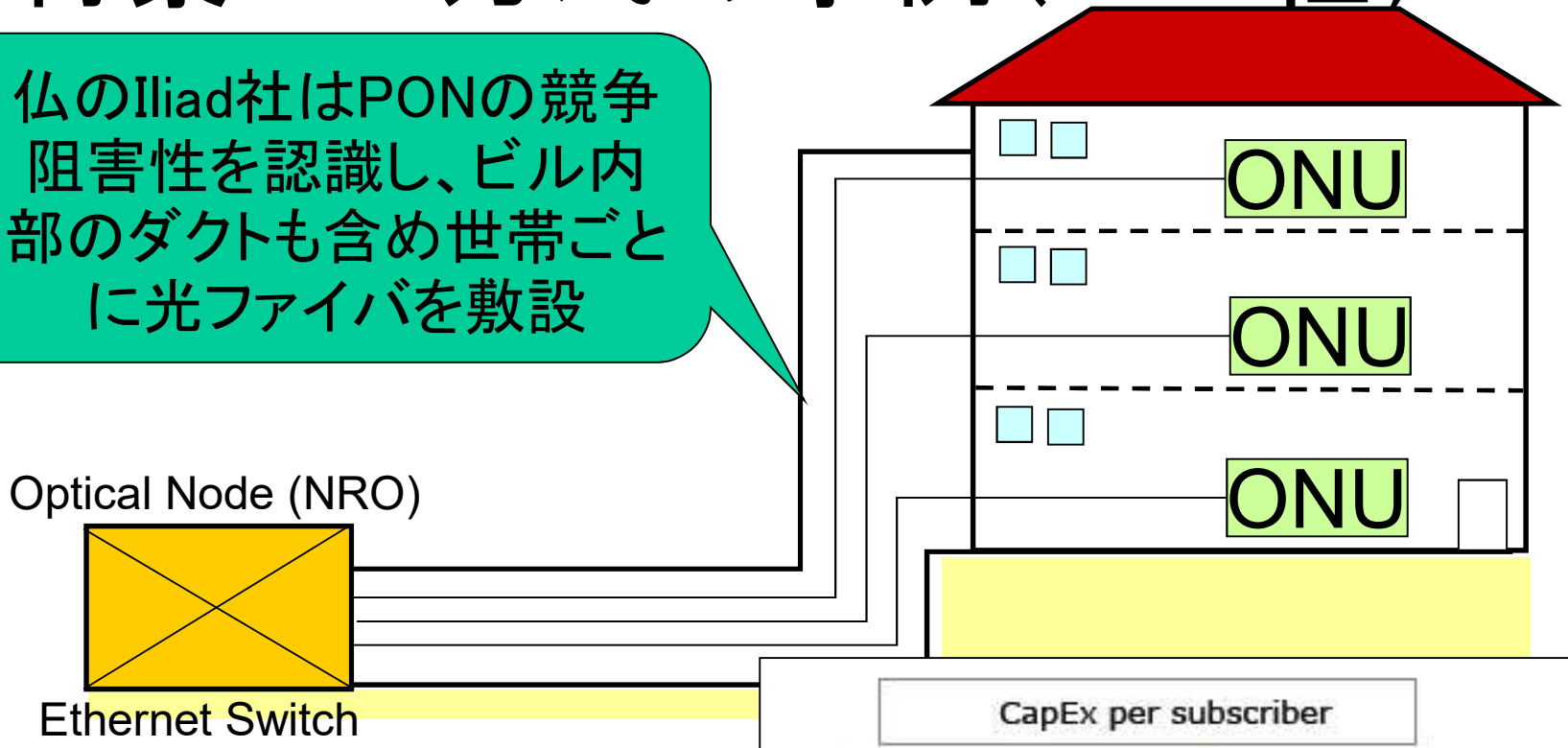
PON with larger share



PON with smaller share

背景　SS方式の事例（Iliad社）

仏のIliad社はPONの競争阻害性を認識し、ビル内部のダクトも含め世帯ごとに光ファイバを敷設



ARCEPによれば、芯線数の節約は、総コストにほとんど寄与していないことが伺える

CapEx per subscriber	
Infrastructure & buildings	€1,000
Optical cable	€50
In-house wiring	€350
Connection	€100
Active network components	€300
Active subscriber components	€200
total	€2,000

出展：http://www.wik.org/content/vdsl_ngn/gauthey.pdf

PONの競争阻害性

光ファイバは狭い光配線区域内に8分岐単位での接続となるため、設備稼働率がサービス提供コストに大きく影響する。

■世帯に占めるブロードバンドユーザー比率　　(*1)ADSL+FTTH

$$= \frac{\text{2200万加入}^{(*1)}}{\text{全国　4700万世帯}} = 47\%$$

■光ファイバの1光配線区域（30世帯を想定）におけるブロードバンド加入世帯

＝　30世帯　×　47％ ＝ **14加入**

効率的に設備共用した場合

事業者A＋B＋C＋Dで設備共用

$$\frac{8}{8} + \frac{6}{8}$$

88%

・参入事業者が増えても稼働率は低下しない
・設備共用によりコストは同じで競争中立的

	事業者A	事業者B	事業者C	事業者D
8分岐稼動数	7	3	3	1
稼働率	87%	37%	37%	13%

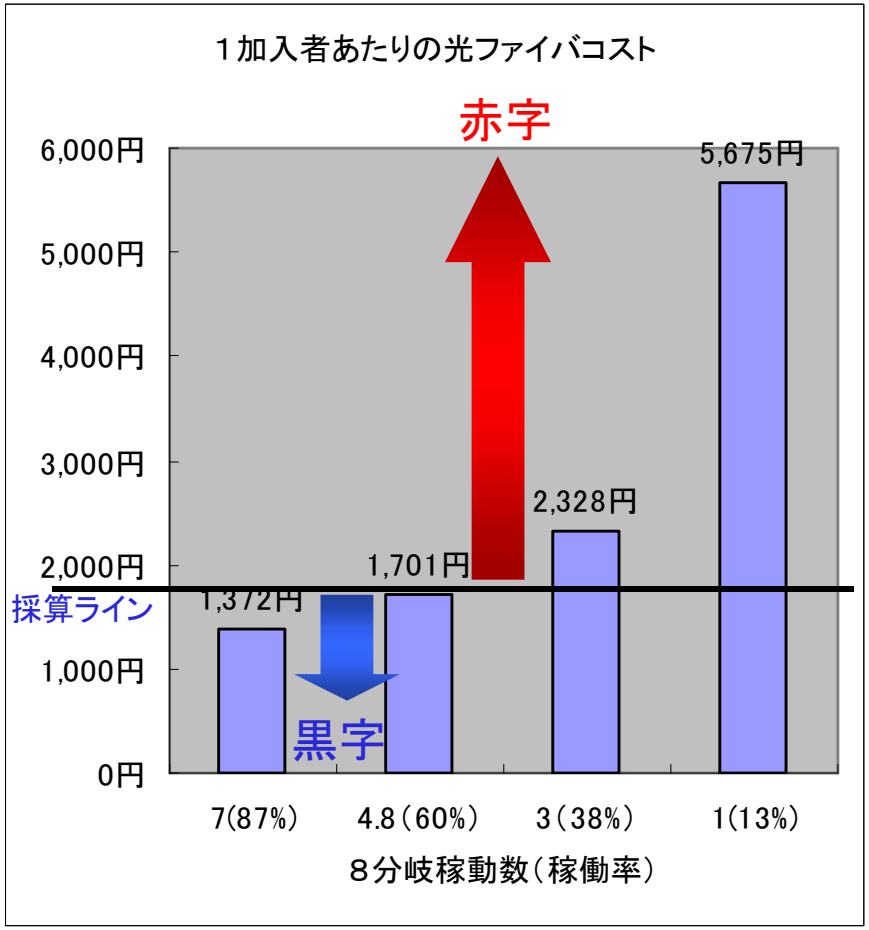
現状（事業者毎に8分岐設備を利用）

・参入事業者が増加するほど、個々の稼働率は低下し、コストが増加するため実質的な参入制限となる。
・獲得した加入者数によりコストが固定化し、稼働率を確保できない競争事業者は赤字でのサービス提供を強いられるため非競争中立的であり、独占性を助長する市場となる。

現状のFTTH市場は事業者毎に8分岐設備を利用しているため、構造的に公正競争が行われない状態にある

PONの競争阻害性

設備稼働率が低いと1加入者あたりの光ファイバコストが高くなる。



■1競争事業者の設備稼働率

13%(事業者D)

1加入者あたり 5,675円

37%(事業者B、C)

1加入者あたり 2,328円

87%(事業者A)

1加入者あたり 1,372円

■NTT東西の設備稼働率
(接続料算定、Bフレッツのスタックテストにおけるコスト)

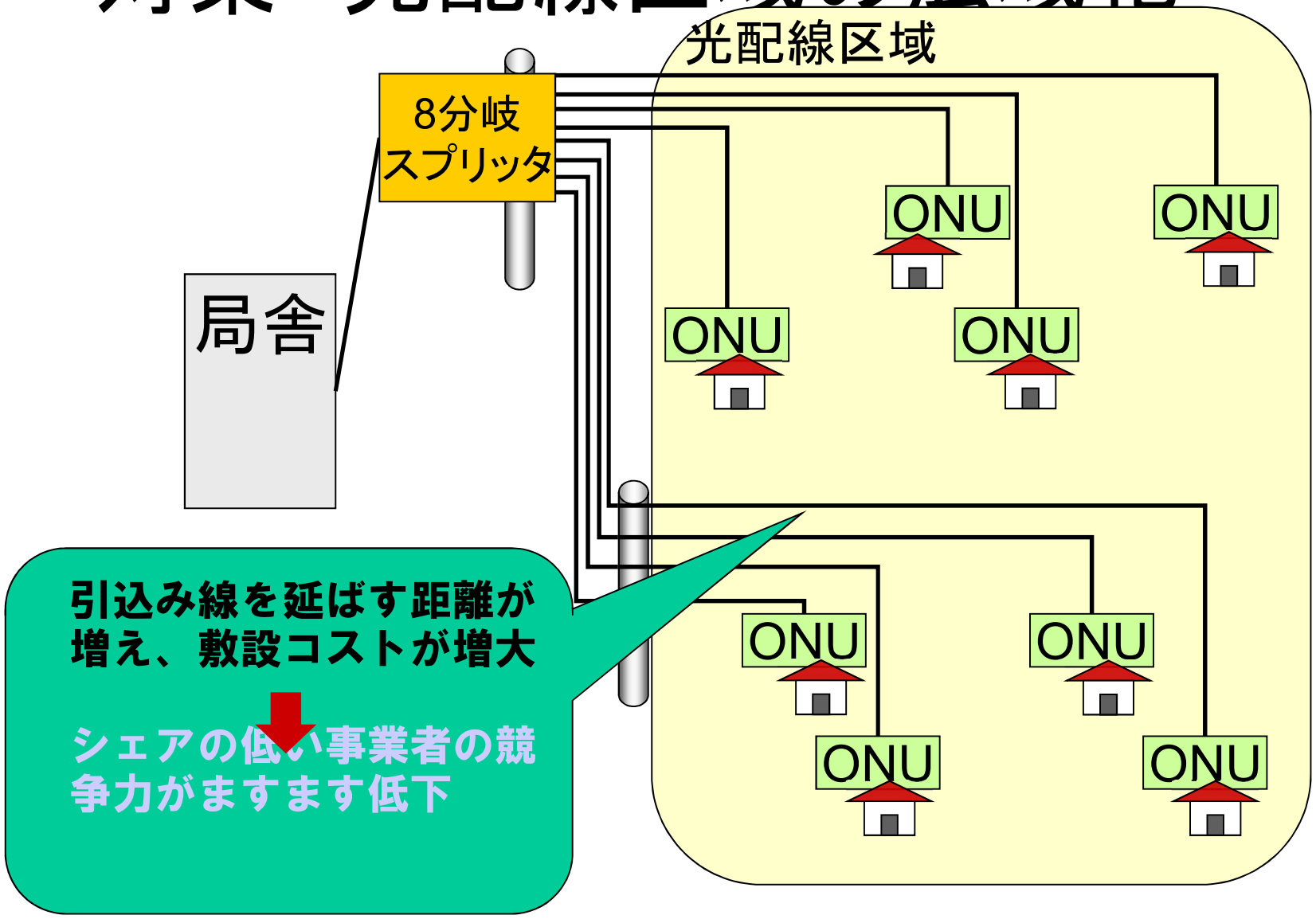
＝ 60%(*1)

1加入者あたり 1,701円

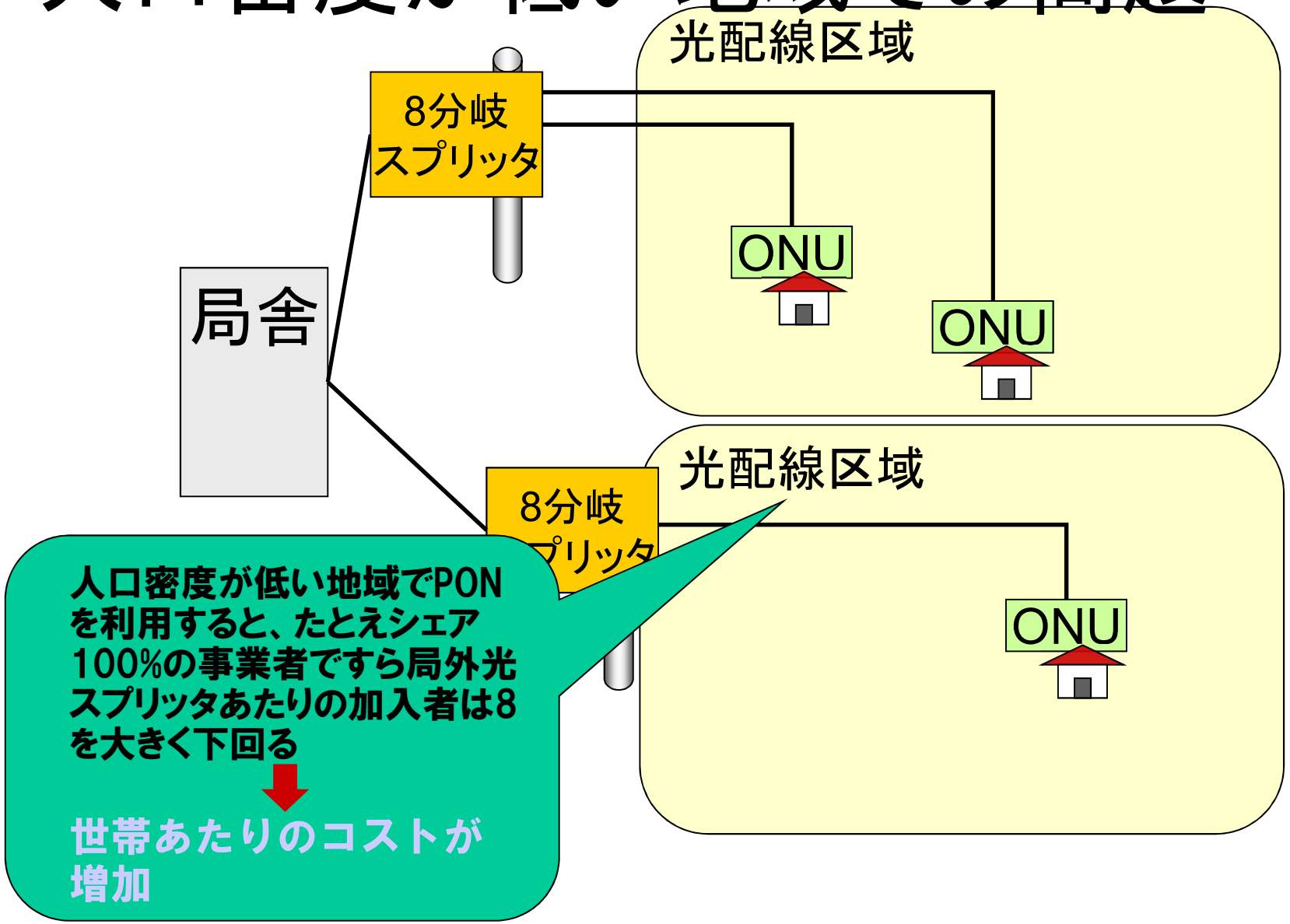
獲得した加入者数によりコストが固定化し、稼働率を確保できない競争事業者は赤字でのサービス提供を強いられる

(*1) http://www.soumu.go.jp/s-news/2003/030129_4.html

対策　光配線区域の広域化

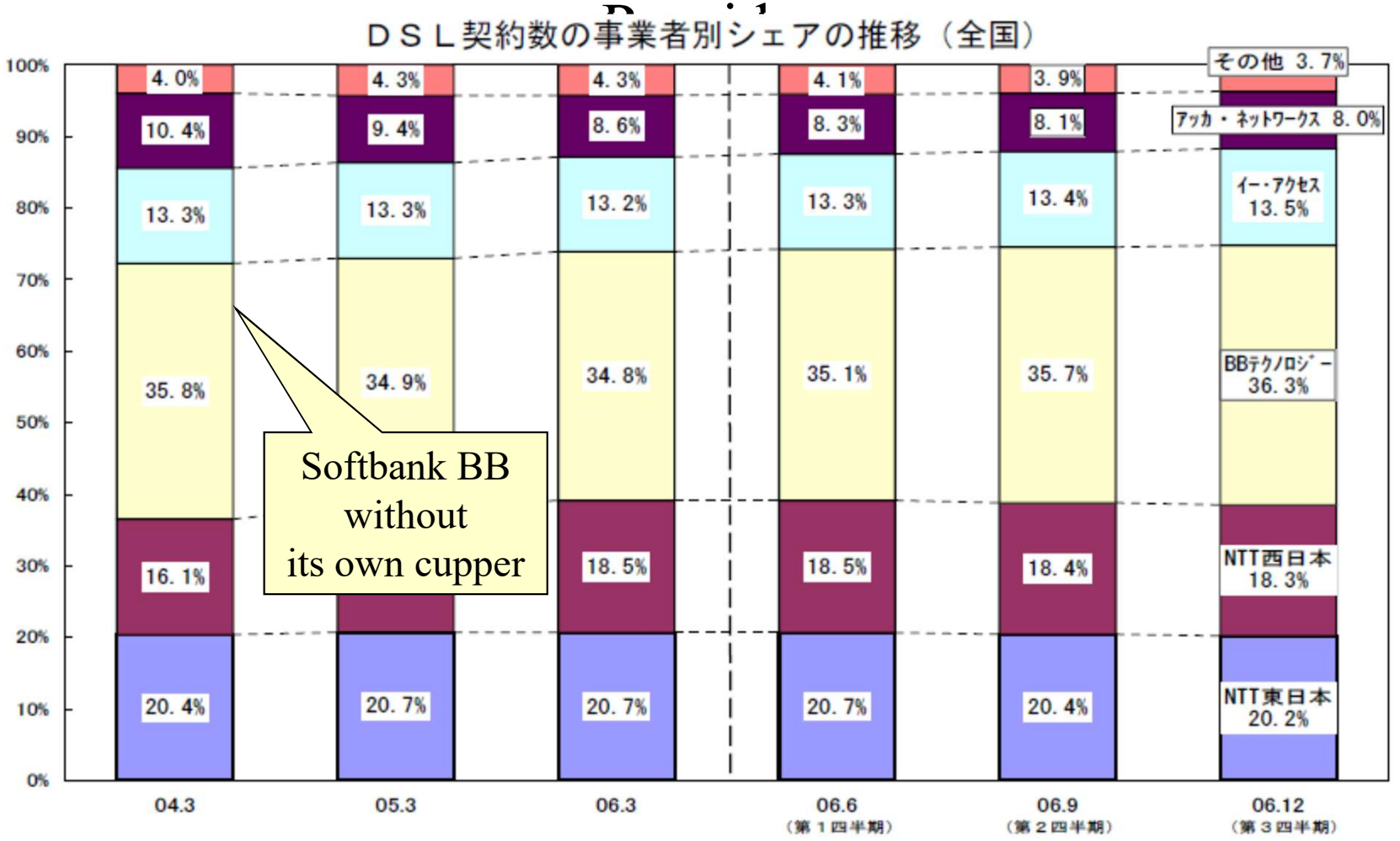


人口密度が低い地域での問題



DSL Services in Japan

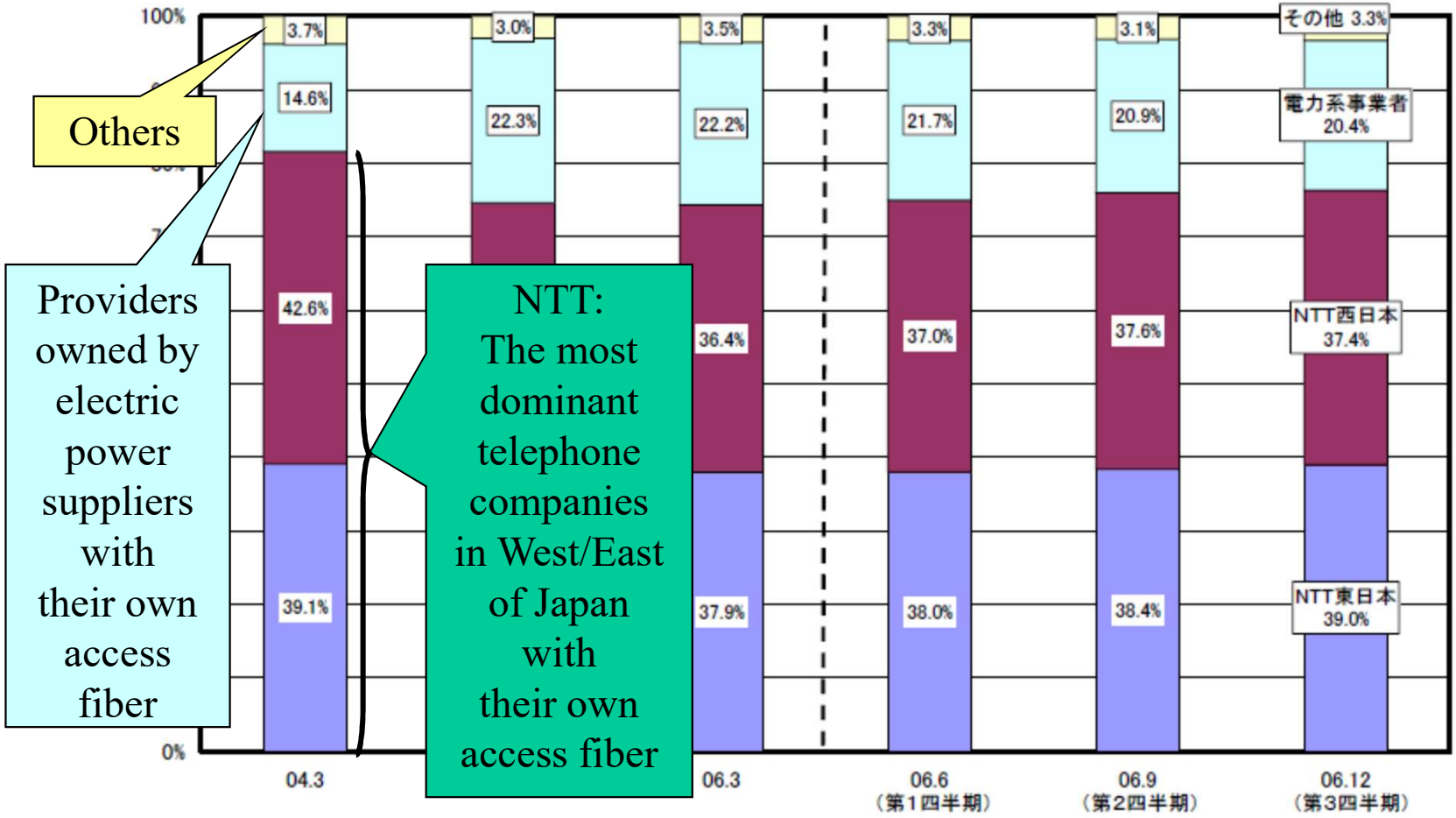
Highly Competitive between Multiple Service



FTTH Services in Japan

Dominated by Service Providers owning Access

ＦＴＴＨ契約数の事業者別シェアの推移（戸建て＋ビジネス向け）



提案方式1の考え方

1. 光ファイバにつながる加入者数に応じてアンバンドル料金を算定する方法

■従来の算定方法（加入者回線の月額料金）

加算料相当コスト控除後原価
÷（芯線数 or 設備数）÷12ヶ月
＝
光信号主端末回線の芯線数

■提案方式（加入者回線の月額料金）

加算料相当コスト控除後原価
÷需要が見込まれる回線数÷12ヶ月
＝
光信号分岐端末回線の芯線数

加算料相当コスト控除後原価	8267億3700万円
加入者回線	1773万9000本
稼働率	60%
引き込み回線	8514万7200本

表　提案方式による月額アンバンドル料金

スプリッタごとの回線数（単位：本）	アンバンドル料金（単位：円）
1	810
2	1,619
3	2,427
4	3,238
5	4,046
6	4,855
7	5,664

Future of the Internet

- primarily by optical fiber
  - overwhelmingly high speed (>>1Tbps/core)
- wireless is still necessary
  - wireless backbone (one to many)
    - broadcast internet by satellite
      - killer application should be that of broadcast network
  - wireless access (no wiring necessary)
    - mobile internet
      - killer application should be that of phone network
        - » free conversation!

Radio Waves and the Internet

- short distance (low power)
  - install many stations (not phone network of 5G)
  - mobile internet service can be realized by IP mobility
- long distance (high power)
  - radio waves are good for one to many
  - is satellite internet fast?
    - fast only for one to many

Broadcast Network

- Network to Transfer Voice/Image to Many in Realtime
  - Allocate bandwidth for the transfer
  - Minimize delay
- Wide Area One to Many Communication over Radio Waves
  - Broadcast/Multicast
- Protected by Broadcast Act

Satellite Internet Broadcast

- transmit IP packets over radio waves
  - not merely satellite digital broadcast
  - IPパケットを電波にのせる
  - smoothly integrate with home IP network
- one to many!
  - one to many over the Internet is multicast
  - transmit IP multicast packets over radio waves

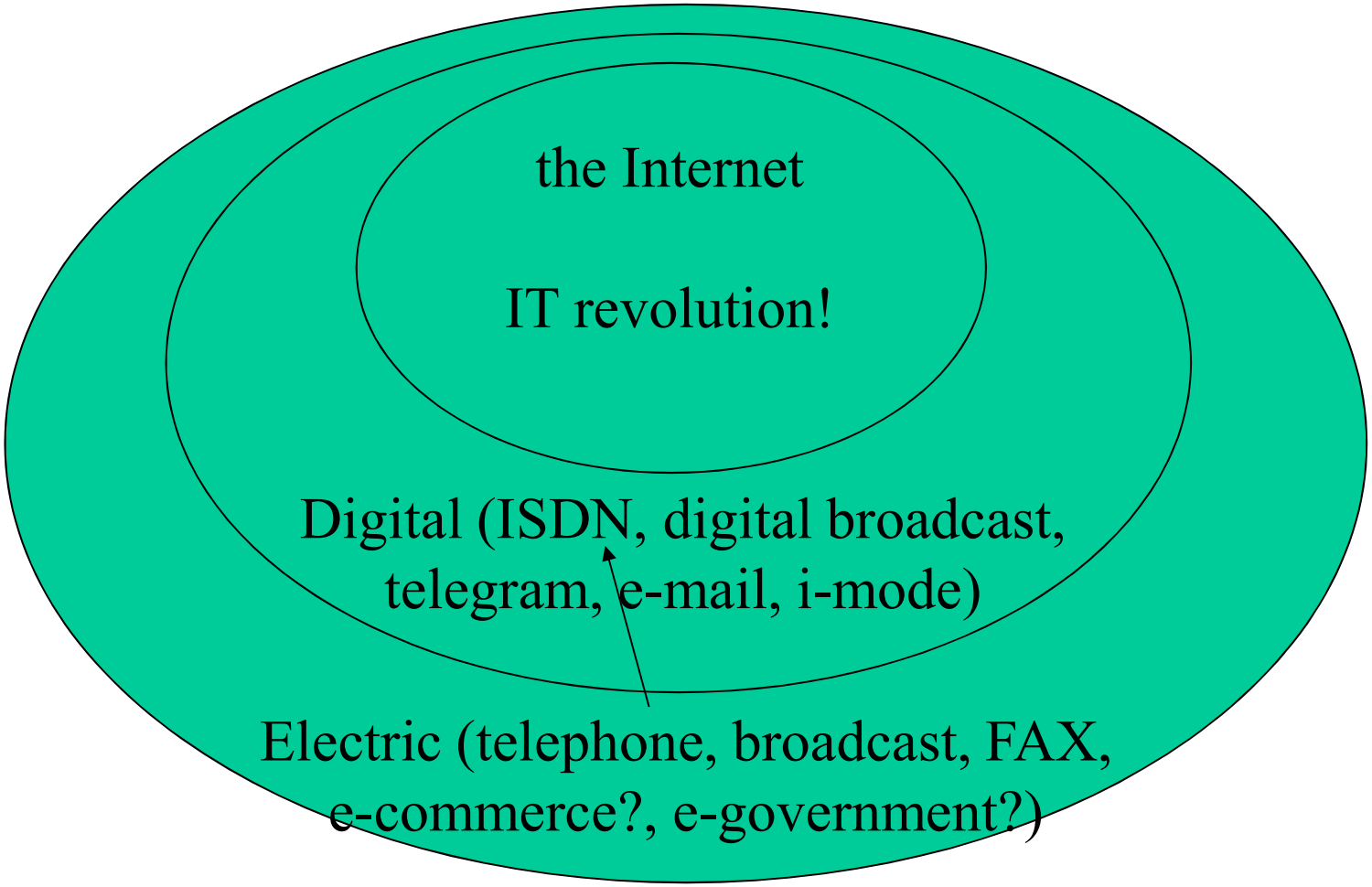
High Speed Internet by Satellite?

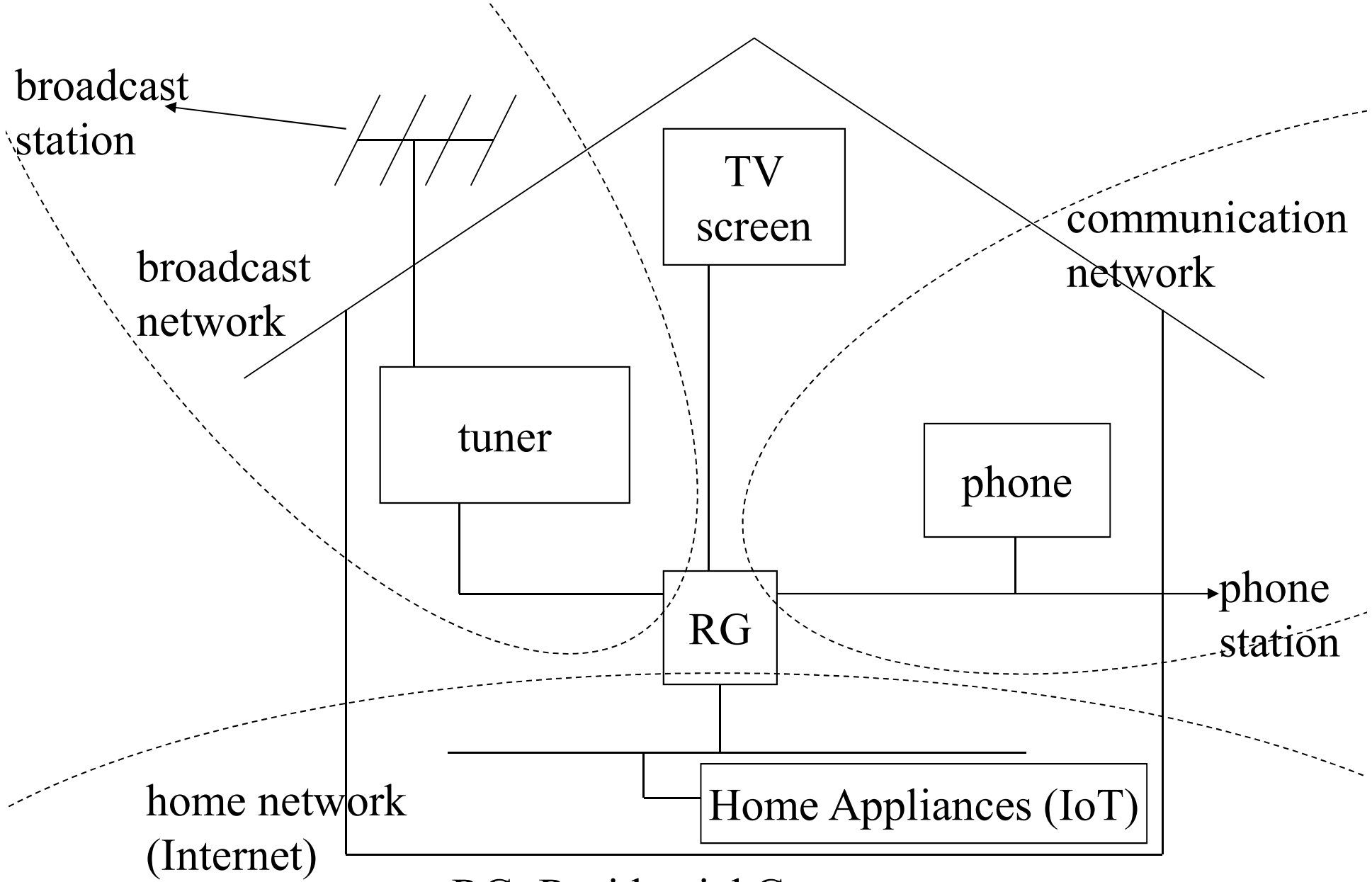
- satellite communication is really expensive
  - millions of $/year @ several tens of Mbps
  - satellite bandwidth should be shared by many
- large scale one to one communication by satellite is impossible
  - 4kbps*(1M subscibers)=4Gbps!
  - iridium (mobile phone by satellite) bankrupted
    - high speed one to one by satellite is expensive
      - low speed for isolated islands: marginally commercial
        - » expensive but better than nothing

Radio Wave Broadcast by the Internet

- radio wave broadcast by the Internet
  - mere digitization is not meaningful
    - integration of information/communication/broadcast network by the Internet
  - for the integration, radio wave broadcast data must be that of the Internet
    - end to end principle!
  - must use IP over radio wave broadcast
    - because it's one to many, IP multicast packets only

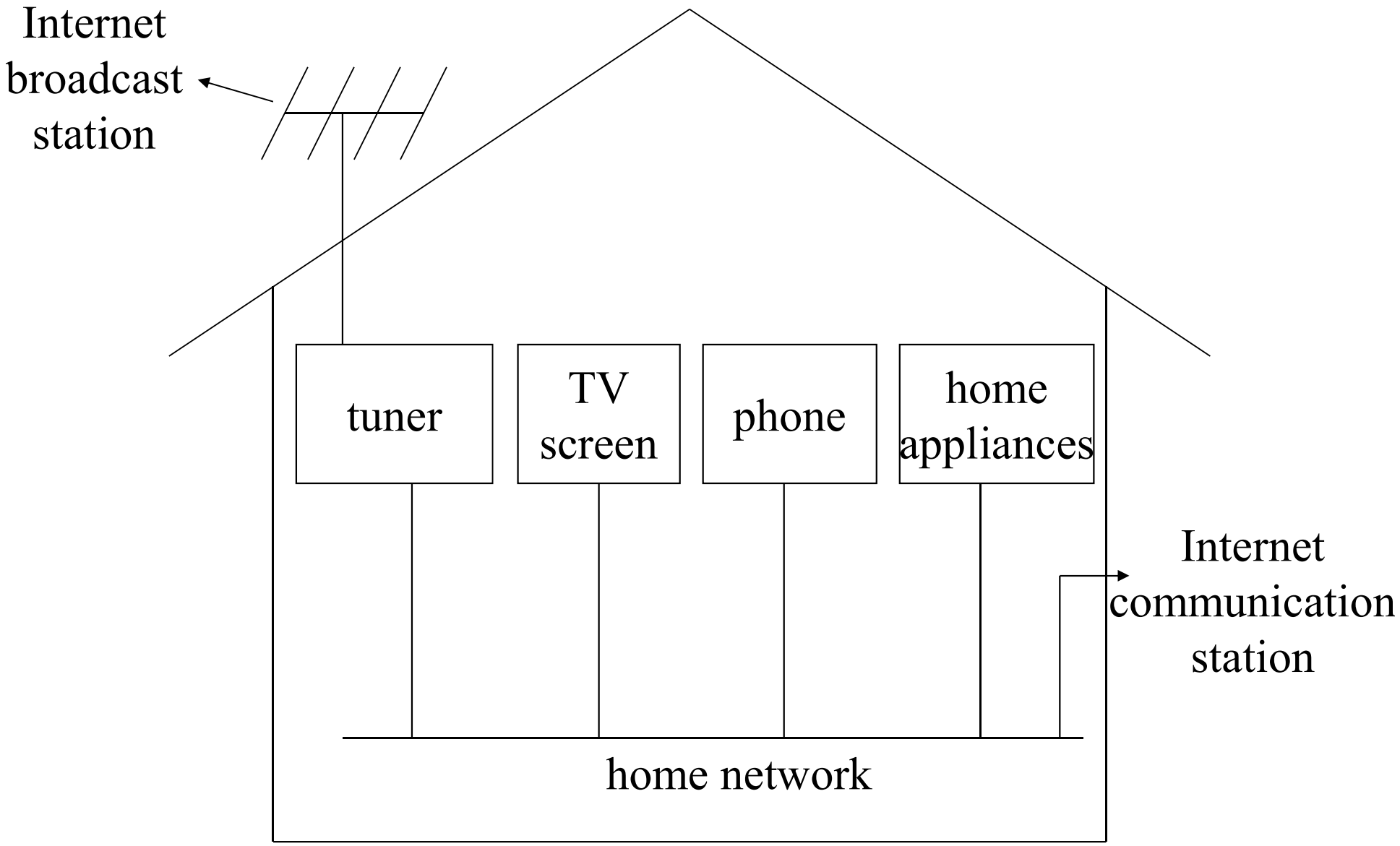
What is the Internet (E, D and I)





RG: Residential Gateway

integration of communication, broadcast and home network?



integration of communication, broadcast and home network!

The Mobile Internet

- mobile phone network is phone network
  - ￥0.3/128B means ￥20/sec @ 64kbps
- radio stations connected to wired high speed inexpensive flat rated internet service
  - wireless high speed inexpensive flat rated internet
  - security improvement necessary (802.11ai)
- wireless internet + IP mobility = the mobile internet

The Mobile Internet

- wireless Internet + IP mobility
  - free movement around a single station by wireless communication
  - IP mobility keeps same IP address and TCP connection upon station changes

Wireless Internet

- needs wired Internet infrastructure
  - by densely installed optical fiber
    - FCC once claimed wireless only is enough, but,
  - high speed inexpensive radio stations attached to wired high speed inexpensive flat rated internet
    - inexpensive flat rated wireless internet
  - if stations are dense enough
    - high speed inexpensive flat rated wireless internet

Technical Problems of the Wireless Internet

- wireless can be used by general public
  - authentication
    - good that anyone can use the internet anytime/anywhere
    - no good if users are not identified
      - crime investigation
      - charge money
  - encryption
    - basically should be end to end
    - good for old protocols with plain text password

Frequency Auction

- promote monopoly, if supply is insufficient
  - frequency resource is not scarce but wasted
    - UHF and analog high vision broadcasting
    - 供給を十分にしないと独占の是認になる
- should collect money from those already using frequency (TV broadcast stations)
  - should charge money proportional to bandwidth and service area
    - current frequency taxation is broken (mostly proportional to # of stations)

Wrap Up

- physical layer of the Internet: faster is better
- optical fiber and radio waves will be the only physical layer
  - optical fiber offer almost infinite bandwidth
    - complicated physical/datalink layer by PON is just harmful
  - mobile terminals needs radio waves
    - allocation of bandwidth is important political issue
  - radio wave broadcast may still be necessary
    - though mere digitization is not enough