



経路制御(2)

● 情報ネットワーク論I



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アウトライン

● IGP と EGP

- ・ドメイン内ルーティング、ドメイン間ルーティング

● 距離ベクトル型 (Distance vector)

● リンク状態型 (Link state)

● パスベクトル型 (Path vector)

● BGP

● 経路の集約

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まず前回の補足

- Topology – **1**: topographic study of a particular place; specifically: the history of a region as indicated by its topography

2a (1): a branch of mathematics concerned with those properties of geometric configurations (as point sets) which are unaltered by elastic deformations (as a stretching or twisting) that are homeomorphisms

(2): the set of all open subsets of a topological space

b: configuration <topology of a molecule> <topology of a magnetic field>

(Source: Merriam-Webster Online Dictionary)

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FIB (Forwarding Information Base) の例

```
zebra@2:na1st# show ipw6 route
Codes: K - kernel route, C - connected, S - static, R - RIPng, O - OSPFv3,
       B - BGP, * - FIB route.

K* ::/0                                fe80::210:5aff:fe7a:b3d1
K* ::/96                                ::1
C* ::1/128                             lo0
K* ::ffff:0.0.0.0/96                  ::1
O* 2001:200:0:840::/64                fe80::210:5aff:fe7a:b3d1
O* 2001:200:0:822::/64                fe80::210:5aff:fe78:cae
C* 2001:200:0:823::/64                fxp0
O* 2001:200:0:823::/64                fxp0
C* fe80::2::/64                       fxp0
C* fe80::3::/64                       xl0
C* fe80::7::/64                       lo0
```

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経路制御の階層化

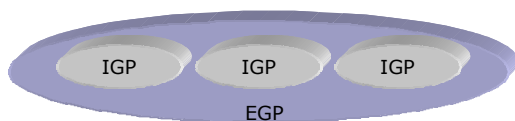
● ルーティングドメイン (routing domain)

- 境界を定義

- 障害の分離、経路の集約 (後述) などの効用

● IGP (Interior Gateway Protocol)

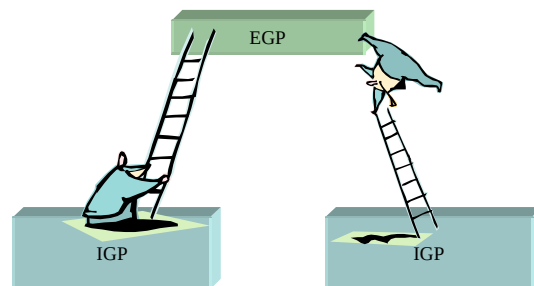
● EGP (Exterior Gateway Protocol)



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Two-tier routing



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IGPs and EGPs

- IGP
 - RIP-2, RIPng, OSPF, IS-IS
 - Distance vector, link state
 - 各リンク・ルータの状態をできるだけ早く伝播させることに主眼
- EGP
 - BGP4, BGP4+
 - Path vector
 - Internet 全体の経路制御の安定性に主眼

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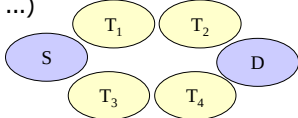
パスベクトル型経路制御

- Bellman-Ford algorithm からの派生形
- 距離ベクトル型で交換する情報:
 - (prefix, metric)
- パスベクトル型で交換する情報:
 - (prefix, path, attributes)
- 距離だけでなくパス情報を経路情報に付与
 - → ループの起きない経路制御が可能

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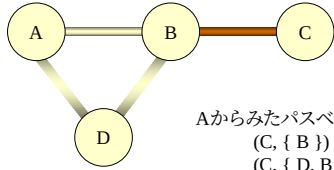
Path vector

- SからみたDへの経路の表現
 - $(D, \{T_1, T_2\}, \dots)$
 - $(D, \{T_3, T_4\}, \dots)$
- 
- パスベクタ長が距離として用いられる
 - パスベクタ長の短い経路を優先

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Loop-free nature of path-vector routing

- 
- Aからみたパスベクタ:
 $(C, \{B\})$
 $(C, \{D, B\})$
- ・リンクB-Cが落ちた場合、Bがパスベクタを取り消し
 - ・ループを回避
 - ・自らが含まれるパスベクタを棄却

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BGP: Border Gateway Protocol

- パスベクトル型の経路制御プロトコル
- トランスポート層プロトコルとしてTCPを利用
 - 再送、確認応答はTCPに委ねる
- 効率的なパスベクトルの表現
- 経路情報の差分を伝播
- 距離情報だけでなくポリシーを表現可能

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パスベクトルの表現

- AS (Autonomous System) を番号で表現
 - ・ AS: 一貫したポリシーを持ったルーティングドメイン
- (prefix, AS-path, attributes) をまとめて符号化
 - ・ $(AS-path, attributes, \{prefix1, prefix2, \dots\})$
 - 通信量を削減

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パス属性 (Path attributes)

- AS_PATH
- ORIGIN
- NEXT_HOP
- MULTI_EXIT_DISC (aka MED)
- LOCAL_PREF
- ATOMIC_AGGREGATE
- AGGREGATOR

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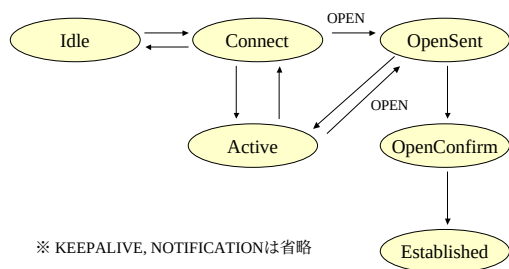


BGP route example

```
show ip bgp 163.221.0.0
BGP routing table entry for 163.221.0.0/16, version 30149334
Paths: (6 available, best #3)
  Not advertised to any peer
  6461 2516 2500 2500
    208.185.175.169 from 208.185.175.169 (216.200.254.220)
      Origin IGP, metric 0, localpref 400, valid, external
    6461 2516 2500 2500, (received-only)
    208.185.175.169 from 208.185.175.169 (216.200.254.220)
      Origin IGP, metric 0, localpref 100, valid, external
  2500, (received & used)
    203.181.70.232 (metric 2) from 203.181.70.232 (203.181.70.227)
      Origin IGP, metric 505, localpref 400, valid, internal, best
      Originator: 203.181.70.227, Cluster list: 0.0.0.16
  2500, (received & used)
    203.181.70.233 (metric 2) from 203.181.70.233 (203.181.70.227)
      Origin IGP, metric 505, localpref 400, valid, internal
      Originator: 203.181.70.227, Cluster list: 0.0.0.16
  2500
    202.249.2.1 from 202.249.2.1 (203.178.136.4)
      Origin IGP, metric 1010, localpref 400, valid, external
  2500, (received-only)
```



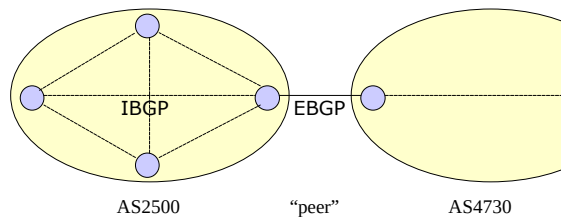
BGPの状態遷移



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IBGP and EBG



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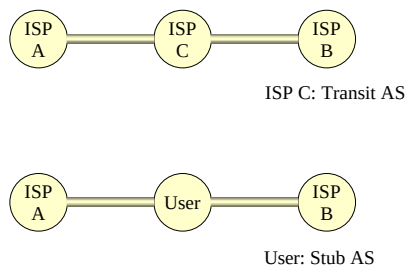
IBGP, EBG の構成要件

- IBGP
 - 同一AS内のすべてのIBGPルータとメッシュ状に peer を確立しなければならない
 - すべてのIBGPルータが同じ情報を持つ
- EBG
 - 隣接ASのEBGPルータと物理的に隣接しなければならない (原則として)
 - 隣接ASと同じ情報を持つ必要はない

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Transit AS, stub AS



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経路制御におけるポリシー

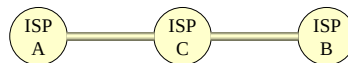
- 広告ポリシー
 - ・ 隣接ルータに広告してよい経路
 - ・ 告知すべきでない経路
 - ・ 広告前の、メトリック、パス属性の操作
- 受け入れポリシー
 - ・ RIBに反映してよい経路、反映すべきでない経路
- 採用ポリシー
 - ・ 複数のRIBのうちどれを優先しFIBに採用するか
- 再配布ポリシー
 - ・ RIB間での経路の変換、再配布
 - ・ 再配布してよい経路、再配布時のメトリック

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トランジットASのポリシー

- ISP C:
 - Accept all routes from ISP A
 - Advertise all routes to ISP B
 - Accept all routes from ISP B
 - Advertise all routes to ISP A



ISP C: Transit AS

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Stub ASのポリシー

- Accept ISP A's route from ISP A
- Advertise user's routes to ISP B
- Accept ISP B's route from ISP B
- Advertise user's routes to ISP A



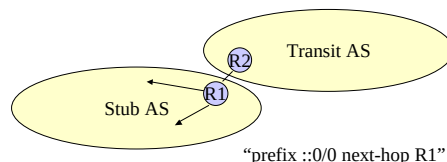
User: Stub AS

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Default route

- 0.0.0.0/0 (IPv4), ::0/0 (IPv6)
- Longest-match → 経路検索の最後にマッチ
- 経路の隠蔽、経路数の削減に効果



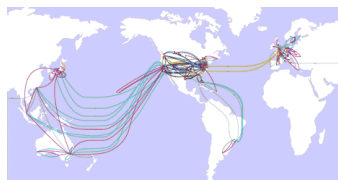
"prefix ::0/0 next-hop R1"

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Default-free

- Default routeがない状態
- Tier-1 ISPs, North America backbone



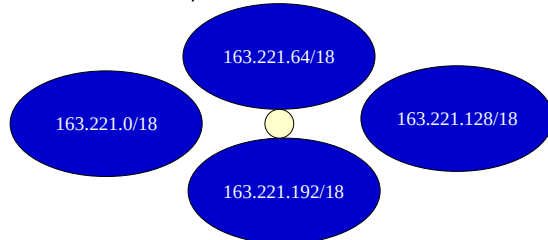
(source: UUNet network maps, www.uu.net)

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経路の集約 (aggregation)

- 163.221.10.0/24 と 163.221.11.0/24 は 163.221.10.0/23 で表現できる

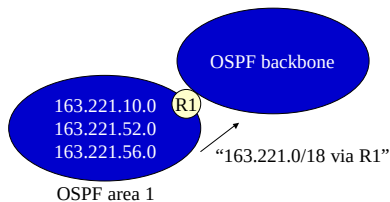


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Aggregation at the border

- 経路の集約はルーティングドメインの境界で



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経路集約の問題点

- 集約できるかどうかはアドレス割り当て次第
 - ・ 計画的なアドレス割り当てが重要
- ③ 奈良先端が4研究科になると予想できたか？
- → prefix renumbering
 - ・ 集約できるアドレスへ付け替え
 - ・ 技術開発がおこなわれている
- 経路集約は手作業でおこなう必要がある
 - ・ インターネット全体で120,000経路

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ここまでのまとめ

- 階層化経路制御の考え方
 - IGP, EGP
- パスベクトル型経路制御
- BGP
 - パス属性, AS path, AS番号
 - IBGP, EBGP
- Transit, Stub
 - Default, default-free
- 経路集約 – 考え方、問題点

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インターネット技術の発展

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Internetworking technology developments

- Goal: communication platform for digital convergence
 - Cellular phones
 - Handheld devices
 - Home appliances
 - TV
 - Satellites
 - Space communications
 - Scientific instruments

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Internetworking technology developments

- Meeting the challenges with:
 - Ubiquity
 - More efficient addressing / routing
 - Mobility
 - Plug and play
 - Security
 - Scalable multicast
 - Adaptability

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Internetworking technology developments

- Trend: Interoperability at higher layers
 - interoperation of components
 - standardized messaging at Layer 7
- “Duct pipes” at higher layers
 - Java, Perl, CORBA, XML, ...
- Expect more duct pipes to appear...

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Internetworking technology developments

- Issue: Interoperability of latest developments
 - security + mobility
 - plug&play + adaptability
 - multicast + mobility
 - the list goes on...
- “Duct pipes” at lower layers?

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最後に

- インターネット技術は（専門でなくても）役に立つ
- よい技術を盗み、学び、体験することができる
 - 実在する世界最大の分散システム
 - 規格書もすべてオープン
 - ソフトウェアの実装もオープン
 - それほど複雑ではない

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