Everything you wanted to know about the Babel routing protocol but were afraid to ask

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The Babel protocol

Babel is a loop-avoiding distance-vector protocol:

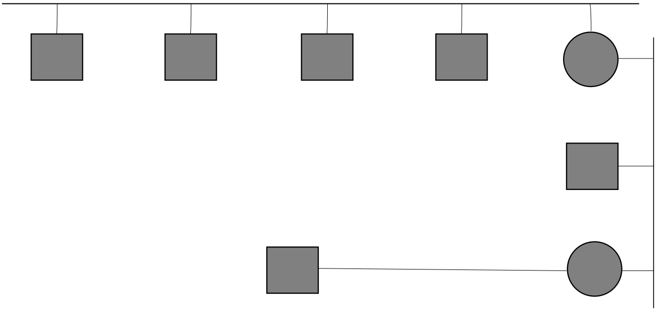
- uses distributed Bellman-Ford;
- an invariant guarantees loop-freedom: feasibility condition guarantees good transient behaviour.

It is a simple protocol:

- RFC 6126 is 45 pages of which 28 are normative;
- independent reimplementation done in 2 nights by M. Stenberg.

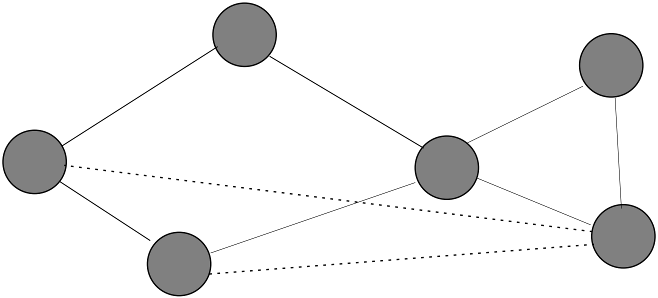
It is a highly extensible protocol — 5 extensions defined (2 RFCs, 3 I-D), all of them interoperate.

Classical networks



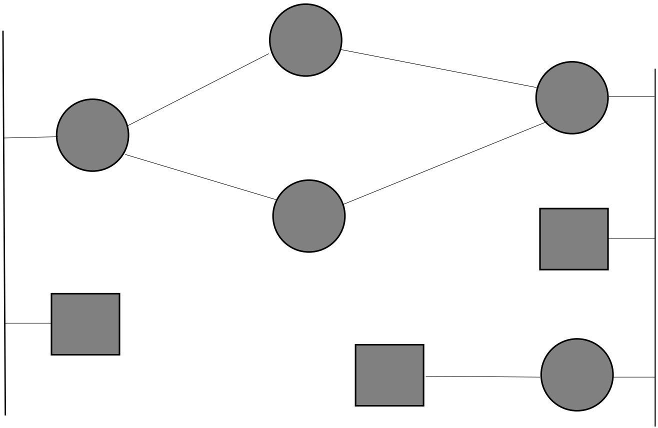
- stable, wired topology;
- transitive links;
- prefix-based routing (optimisation).

Mesh networks



- unstable, wireless topology;
- non-transitive links;
- very variable link quality.

Hybrid networks



- some classical bits, some meshy bits;
- meshy bits used for transit.

Babel

Babel is a protocol designed for hybrid networks: it makes no assumptions about the network topology or behaviour:

- no assumption about topology (all optimisations are optional);
- strong guarantees about behaviour before convergence (loop avoidance).

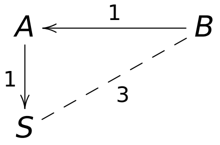
Intuition: Babel pushes packets in roughly the right direction using loop-free paths. Not much can go wrong.

Ratel
Honey Badger

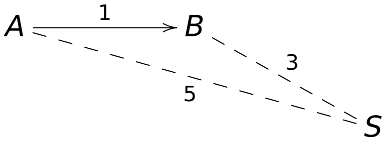
« Babel doesn’t care »

Example of transient routing loop

Link-state protocol



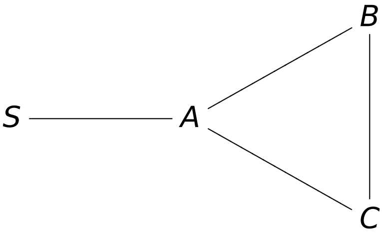
A uses the direct route to *S*
B goes through *A*



A switches to the route through *B* before *B* has switched to the direct route

This transient situation will persist until the topology change is successfully flooded to *B*.
With Babel, *A* will delay switching routes until it can be sure that *B* has switched to the direct route.

Distributed Bellman-Ford (1)



S	0	0	0	0
A	∞	1, nh $= S$	1, nh $= S$	1, nh $= S$
B	∞	∞	2, nh $= A$	2, nh $= A$
C	∞	∞	2, nh $= A$	2, nh $= A$

Converges in $O(\Delta)$.

Distributed Bellman-Ford (2)

Initially,

$$\mathrm{d}(S) = 0 \qquad \mathrm{d}(X) = \infty$$

Often enough, Y broadcasts $\mathrm{d}(Y)$ to its neighbours.
When X receives $\mathrm{d}(Y)$,

- if $\mathrm{nh}(X) = Y$,

$$\mathrm{d}(X) := c_{XY} + \mathrm{d}(Y)$$

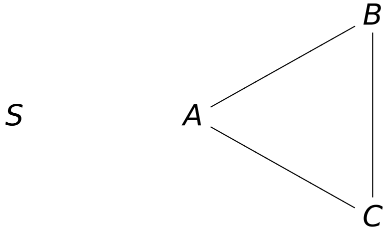
- if $c_{XY} + \mathrm{d}(Y) < \mathrm{d}(X)$

$$\mathrm{d}(X) := c_{XY} + \mathrm{d}(Y) \qquad \mathrm{nh}(X) := Y$$

Timeout: if $nh(X) = Y$, and Y stops broadcasting,

$$\mathrm{d}(X) := \infty \qquad \mathrm{nh}(X) := \bot$$

Distributed BF: counting to infinity



A	1, nh $= S$	3, nh $= B$	3, nh $= B$	3, nh $= B$
B	2, nh $= A$	2, nh $= A$	3, nh $= C$	3, nh $= C$
C	2, nh $= A$	2, nh $= A$	2, nh $= A$	4, nh $= A$

Converges in $O(\infty)$. (RIP: $\infty = 16$.)

Before convergence, there is a routing loop.
« Good news travel fast, bad news travel forever. »

BF: Feasibility conditions

BF is robust, we can ignore updates if they risk generating a loop.

When X receives $(\mathrm{d}(Y), f)$,

- if $\mathrm{nh}(X) = Y$ and $\text{feasible}(Y, \mathrm{d}(Y), f)$

$$\mathrm{d}(X) := c_{XY} + \mathrm{d}(Y)$$

- if $c_{XY} + \mathrm{d}(Y) < \mathrm{d}(X)$ and $\text{feasible}(Y, \mathrm{d}(Y), f)$

$$\begin{aligned} \mathrm{d}(X) &:= c_{XY} + \mathrm{d}(Y) \\ \mathrm{nh}(X) &:= Y \end{aligned}$$

where feasible is a function that guarantees the lack of loops.

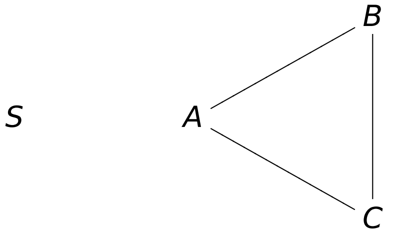
Feasibility conditions

BGP, *Path Vector*:
f is the complete path,
$\text{feasible}(f) = \text{self} \notin f$.

DSDV, **AODV**:
$\mathit{feasible}(d) \equiv c + d \leq \text{d}(\text{self})$
Invariants: $\text{d}(X) \searrow$ and if $A \leftarrow B$ then $\text{d}(A) < \text{d}(B)$.

EIGRP/DUAL, **Babel**:
We maintain $\text{fd}(X) = \min_{t \leq \text{now}} \text{d}(X, t)$.
$\mathit{feasible}(d) \equiv d < \text{fd}(\text{self})$
Invariants: $\text{fd}(X) \searrow$ and if $A \leftarrow B$ then $\text{fd}(A) < \text{fd}(B)$.

Feasibility: example

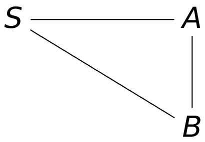


A	1, fd = 1	∞, fd = 1	∞, fd = 1	∞, fd = 1
B	2, fd = 2	2, fd = 2	∞, fd = 2	∞, fd = 2
C	2, fd = 2	2, fd = 2	∞, fd = 2	∞, fd = 2

Converges in $O(\Delta)$.

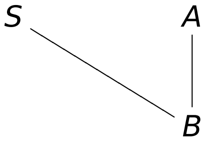
Feasibility: starvation

The feasibility condition may cause starvation.



$d(A) = 1, fd(A) = 1$

$d(B) = 1, fd(B) = 1$



$fd(A) = 1$

$d(B) = 1$

The only available route is not feasible.

Solving starvation

Idea: when no route is available, reboot the whole network.

DUAL/EIGRP makes a global synchronisation (of routes towards S).

DSDV, AODV and Babel use sequenced routes.

Solving starvation: sequenced routes

Route announcements are equipped with a sequence number:

$$(s, \mathrm{d}(B))$$

where $s \in \mathbf{N}$ is incremented by the source:

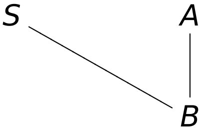
$$\begin{aligned} \mathrm{d}(S) &= (s, 0) && (s \nearrow) \\ c + (s, m) &= (s, c + m) \end{aligned}$$

Define

$$(s, m) \leq (s', m') \quad \text{when} \quad \begin{aligned} & s > s' \text{ or} \\ & s = s' \text{ and } m \leq m' \end{aligned}$$

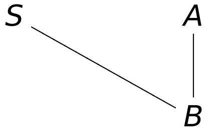
$$\mathrm{feasible}(s, m) \equiv (s, m) < \mathrm{fd}.$$

Sequenced routes: example



S	$(1,0)$	$(2,0)$	$(2,0)$
A	$\infty, \mathrm{fd} = (1,1)$	$\infty, \mathrm{fd} = (1,1)$	$(2,2), \mathrm{fd} = (2,2)$
B	$(1,1), \mathrm{fd} = (1,1)$	$(2,1), \mathrm{fd} = (2,1)$	$(2,1), \mathrm{fd} = (2,1)$

Temporary starvation

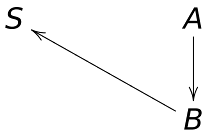


$$
\begin{aligned}
\mathrm{d}(S) &= (1, 0) \\
\mathrm{d}(B) &= (1, 1) \\
\mathrm{d}(A) &= \infty \qquad \mathrm{fd}(A) = (1, 1)
\end{aligned}
$$

A must wait until S generates a new seqno and the network propagates it.
In Babel, temporary starvation is explicity signalled by A ($\neq$ DSDV).

Solving temporary starvation

When a Babel node suffers from temporary starvation (routes available but not feasible) it sends an explicit request for a new seqno.



Unlike AODV, this request is not broadcast, which avoids an increasing horizon search, a simple *hop count* is enough.

Multiple gateways

In general, we want it to be possible to have multiple nodes that announce the same prefix without synchronising sequence numbers.

Babel distinguishes source and destination.

A Babel announce contains a triple

$$(s, d, id)$$

where *id* uniquely identifies the node originating the route. Routes are indexed by source and destination.

Multiple gateways: loops

In the presence of multiple gateways,
Babel no longer guarantees loop-freedom.

$$S_1 \text{ ——— } A \text{ ——— } B \text{ ——— } S_2$$

$$\mathrm{d}(A) = (17, 1) \qquad \mathrm{d}(B) = (43, 1)$$
$$\mathrm{fd}(A, S_1) = (17, 1) \qquad \mathrm{fd}(B, S_2) = (43, 1)$$

We guarantee that a loop disappears in $O(n)$, where n is the size of the loop.

Non-disjoint routes (1)

A routing loop can also occur because of two routes towards overlapping prefixes.

0.0.0.0/0 ——— *A* ——— *B* ——— *C*

The link between *B* and *C* disappears:

0.0.0.0/0 ——— *A* ——— *B*   *C*

If *B* reroutes through *A*, there is a temporary routing loop because the data plane is not aligned with the control plane. This can only happen after a retraction.

Non-disjoint routes (2)

After a retraction, a routing loop occurs because the data plane is not aligned with the control plane.

We must browbeat the data plane into compliance: temporarily install a blackhole route that covers the longer (smaller) prefix and is removed as soon as the prefix is announced again.

This prevents automatic aggregation. (No DRAGON for Babel.)

Loop freedom

Babel is almost loop-free:

1. no loops occur in the absence of multiple gateways;
2. in the presence of multiple gateways, a loop may sometimes occur, but it gets cleared in linear time.

This is a theorem (I have a proof!) with very weak hypotheses:

- causality (a message is never received before it was sent);
- strong monotonicity of the metric.

Like in BGP, isotonicity is not needed. More about that later.

Applicability

Cool technology — but what can it do?

Babel was originally designed for hybrid networks: mostly wired, prefix-based networks with some meshy bits in them.

This implies:

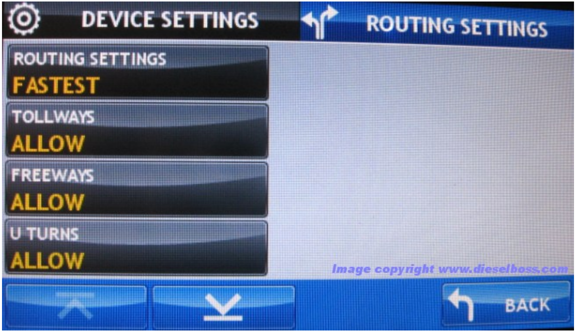
- classic, prefix-based routing is possible and reasonably efficient;
- reasonably fast mobility with delayed and aggregated updates and support for unstable metrics;
- support for non-transitive links.

Babel has been found to be easy to extend:

- RTT-based metric (overlay networks);
- radio-interference metric (non-isotonic);
- source-specific routing (SADR routing).

Metrics

On a GPS, you select the function to optimise:



The function to minimise is called the metric:

- distance: shortest path;
- time: fastest path;
- monetary cost: cheapest path;
- etc.

Metrics

Babel is metric-agnostic. According to RFC 6126,

- a metric MUST be strictly monotonic:

$$m < c \oplus m;$$

- a metric SHOULD be isotonic:

$$\text{if } m \leq m' \text{ then } c \oplus m \leq c \oplus m'$$

Strict monotonicity is enough to guarantee that Babel will converge to a loop-free Nash equilibrium (?). Isotonicity ensures that this equilibrium is actually the tree of shortest paths.

By default, Babel uses:

- hop-count with 2-out-of-3 sensing on wired links;
- ETX (packet loss) on wireless links.

But we can do better.

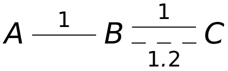
Metrics: radio-interference

Babel-Z3 for wireless meshes

The Z3 metric refines ETX by taking radio interference into account:

$$
\begin{aligned}
M(l \cdot r) &= C(l) + M(r) && \text{if } l \text{ and } r \text{ interfere} \\
M(l \cdot r) &= \frac{1}{2}C(l) + M(r) && \text{otherwise}
\end{aligned}
$$

This metric is not isotonic:

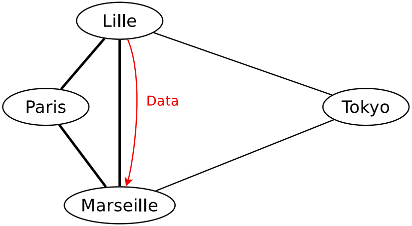


(This is just like BGP with a customer route.)

Metrics: delay

Babel-RTT for Robust Overlay Networks

Nexedi have been using Babel to route in a distributed cloud. Babel requires no configuration.



Hop-count routing has a tendency to route through Tokyo.

Idea: use delay as a component of a routing metric. This causes a feedback loop, which can cause oscillations. While Babel doesn't care, we limit oscillations using a combination of three techniques:

- smoothing of the link cost;
- saturation of the link cost;
- time-sensitive route selection.

Route selection

Route selection: choose the best route among those available.

Goals:

- choose the route with smallest metric;
- prefer stable routes.

These are contradictory goals.

Initially, Babel was overly sensitive to short-term metric variations. Over the years, Babel's route selection policy accumulated increasing amounts of kludges to make it more sticky.

In early 2013, all of this has been scrapped, and Babel has a new route selection algorithm.

History-sensitive route selection

Hysteresis

For each route, we maintain:

- the announced metric M;
- the smoothed metric M_s.

M_s is continuous, and converges exponentially towards M:

$$M_s := \beta(\delta) \cdot M_s + (1 - \beta(\delta)) \cdot M_a$$

with $\beta(\delta)$ chosen so that the time constant is 4 s.

We switch routes:

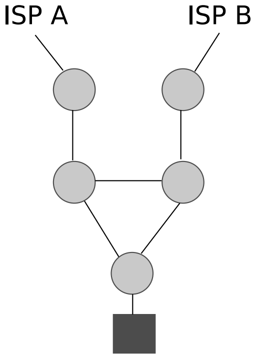
- when the current route is retracted ($M = \infty$);
- when both metrics are better ($M' < M$ and $M'_s < M_s$).

In effect, we do converge to the tree of shortest paths, but take our time switching routes unless we lose our current route. This is a form of hysteresis.

Source-specific routing

Source-specific routing is a modest extension to next-hop routing with wide-ranging consequences.

A packet is routed according to both its source and its destination. The routing table is indexed by destination-source pairs.



Provides a cheap form of multihoming with hostile ISPs. Motivated by the IETF Homenet working group. Works great with MP-TCP.

Conclusions

Babel is a robust and flexible routing protocol:

- reasonable on wired networks (prefix-based);
- reasonable on wireless meshes;
- great framework for experimenting with new ideas:
  - source-specific routing;
  - radio interference-sensitive metrics;
  - delay-based routing.

All of the Babel work is:

- precisely documented (3 RFCs, 3 Internet-Drafts);
- available as open-source software.