THE GEOMORPHIC VIEW OF NETWORKING:

AN ABSTRACT MODEL

AND ITS USES

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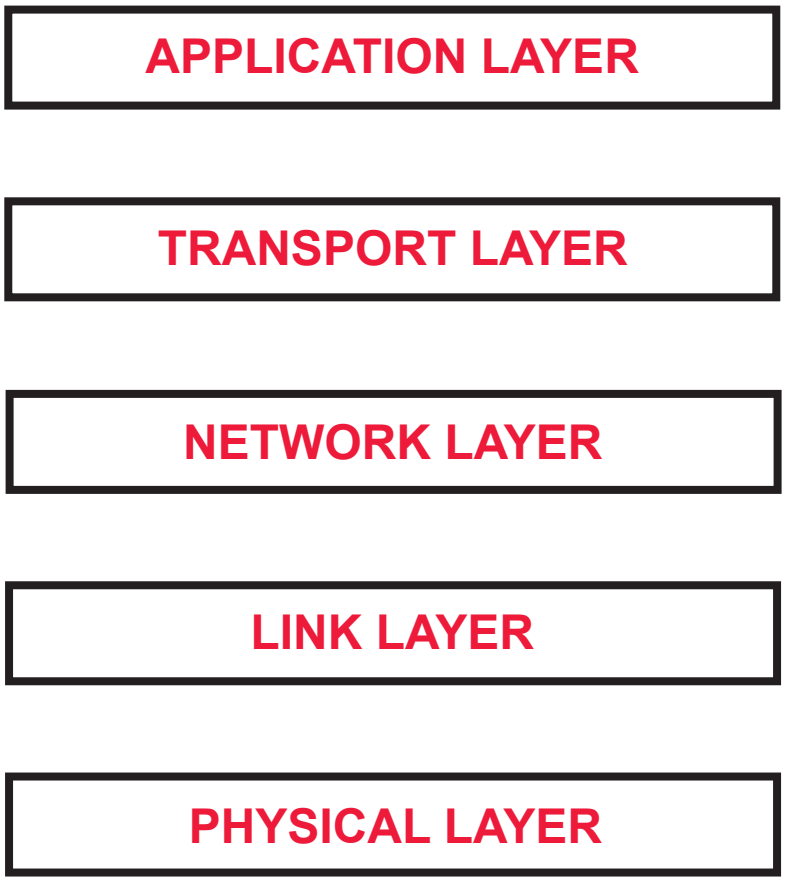
OUTLINE

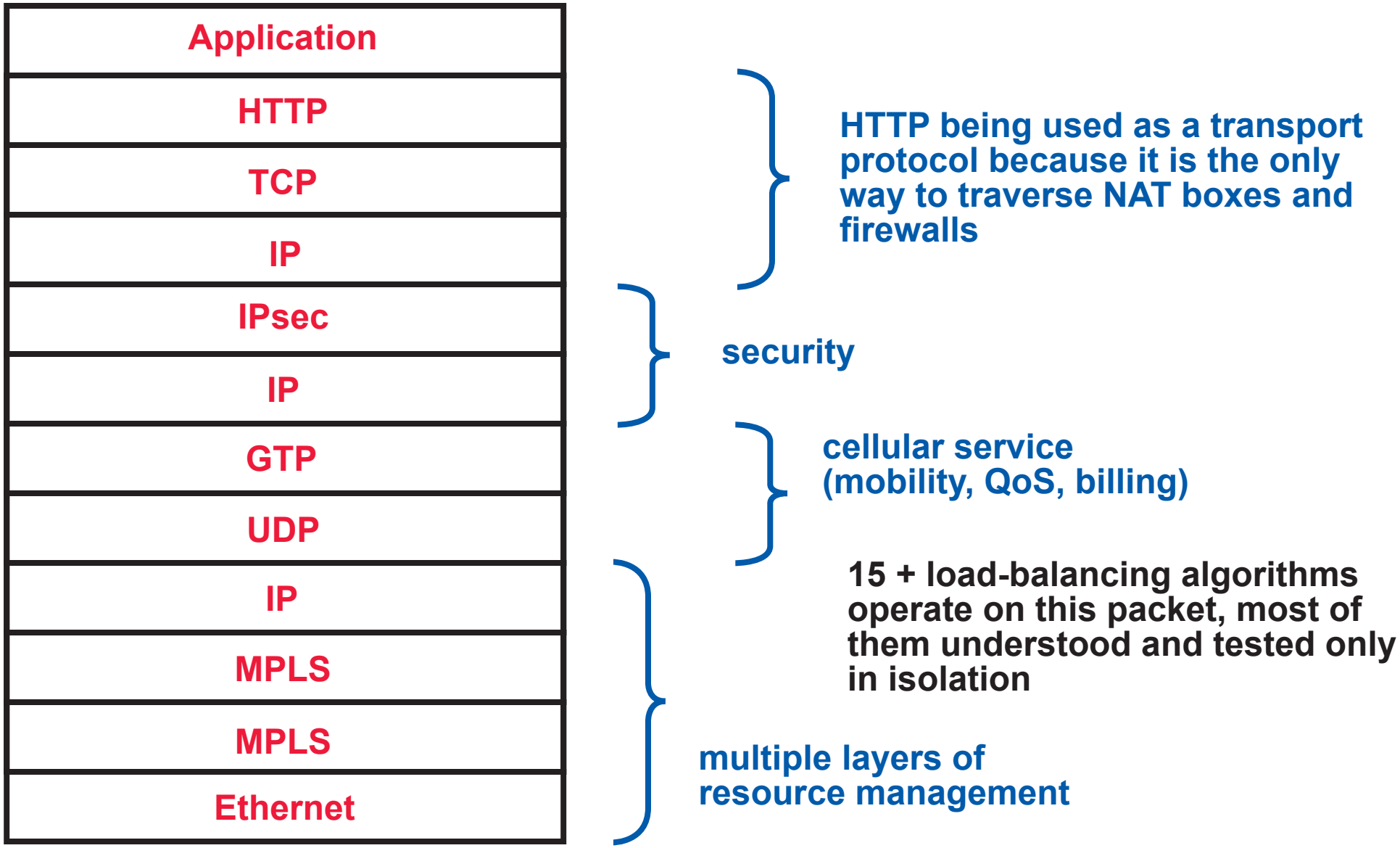
1. MOTIVATION FOR AN ABSTRACT MODEL
2. THE “GEOMORPHIC VIEW” OF NETWORKING
3. THE GEOMORPHIC VIEW OF MOBILITY
   - a. Two patterns for implementing mobility
   - b. A composition theorem
   - c. Evaluation of mobility standards
4. FUTURE WORK

THE “CLASSIC” INTERNET ARCHITECTURE

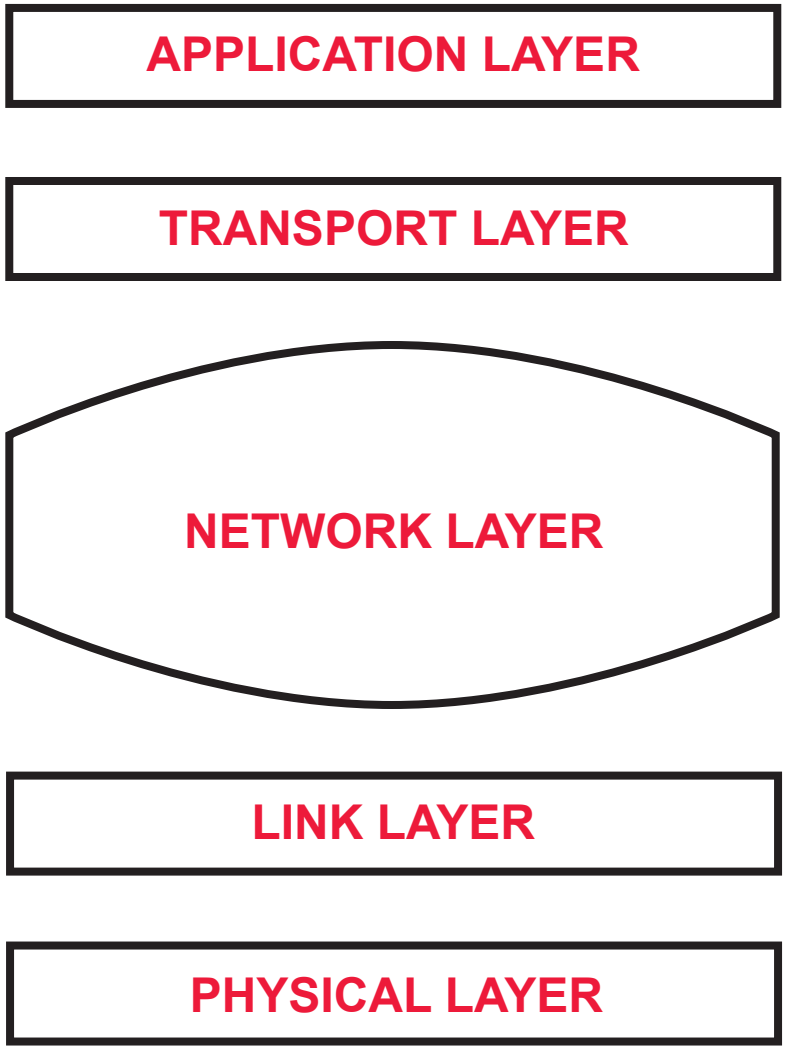


A REAL PROTOCOL STACK

headers in a typical AT&T packet (12 instead of 4)



THE PREVAILING VIEW IN SOFTWARE-DEFINED NETWORKING (SDN)



to be provided by fine-grained routing:

virtualization
mobility
middlebox services
security
multipath routing
load balancing
elastic resource allocation
fault tolerance
bandwidth guarantees
latency guarantees

Nick McKeown says:

One of the major benefits of SDN is a well-defined control abstraction . . . so that software engineering can be applied to its implementation.

software engineering calls for . . .

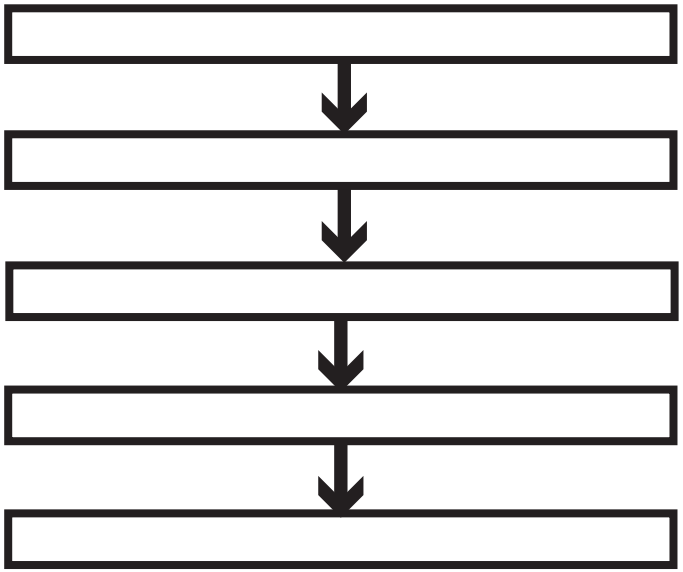
. . . modularity

. . . separation of concerns

CLASSIC LAYERS OR OSI REFERENCE MODEL

there is a fixed number of layers

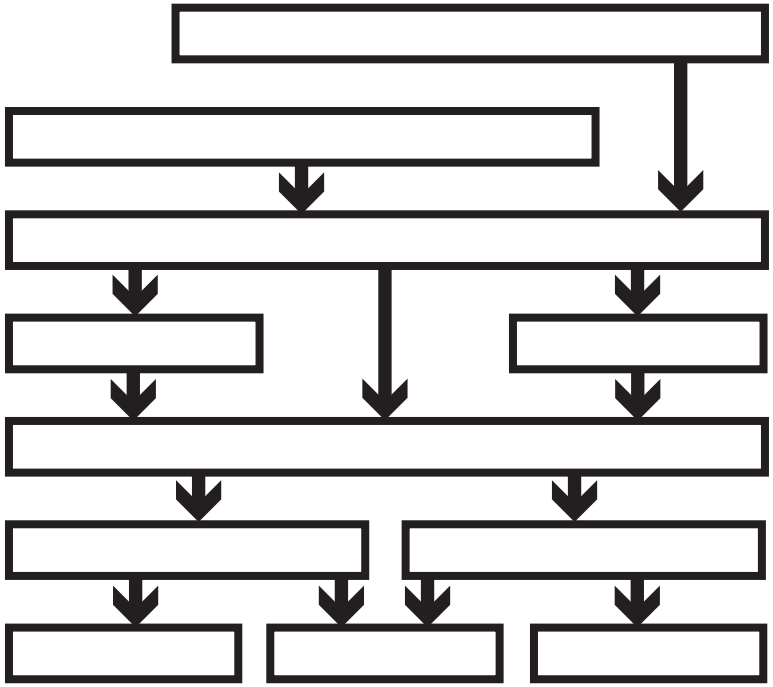
each layer has a distinct and indispensable function



THE GEOMORPHIC VIEW OF NETWORKING

each layer is a microcosm of networking, containing all the basic functions (state components and mechanisms)

there can be any number of levels, each with any number of layers



the layers are modules, providing orderly, fine-grained separation of concerns

POTENTIAL BENEFITS OF LAYERS AS HOMOGENEOUS MODULES

FOR APPLICATIONS

- encourage a richer variety of communication services
- provide well-specified interfaces to these services

FOR RESEARCH PROGRESS

- act as a rigorous description framework in which each proposal has a canonical description, . . .

  . . . allowing proposals to be compared and composed
- serve as a foundation for formal reasoning, . . .

  . . . especially hierarchical reasoning

FOR DESIGN

- manage complexity through separation of concerns followed by composition of concerns
- achieve many diverse goals for diverse stakeholders, all within the same system
- facilitate recognition of . . .
  . . . recurring patterns
  . . . design principles
  . . . structured trade-off spaces

FOR IMPLEMENTATION

- implement implicit layers efficiently, but recoverably
- encourage development of re-usable . . .
  . . . implementation mechanisms
  . . . algorithms for optimization and code generation

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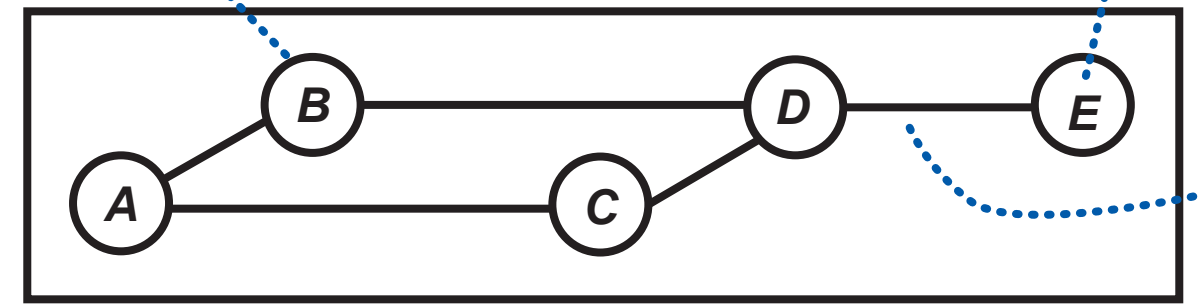
A NEW LAYER MODEL: MEMBERS, ROUTING, AND FORWARDING



forwarding protocol enables members to send messages to one another, using the links

routes routes tell the forwarding protocol how to reach one member from another over the existing links, with forwarding by intermediate members

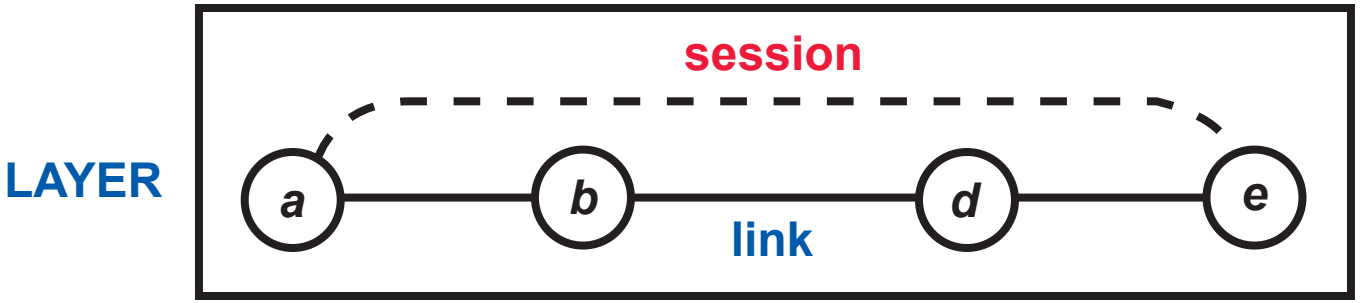
routing algorithm maintains the routes as links change over time

A NEW LAYER MODEL: COMMUNICATION SERVICES

channel an instance of a communication service

session a communication channel (as is a link)

session protocol implements an end-to-end communication service, on top of the basic message delivery provided by the forwarding protocol

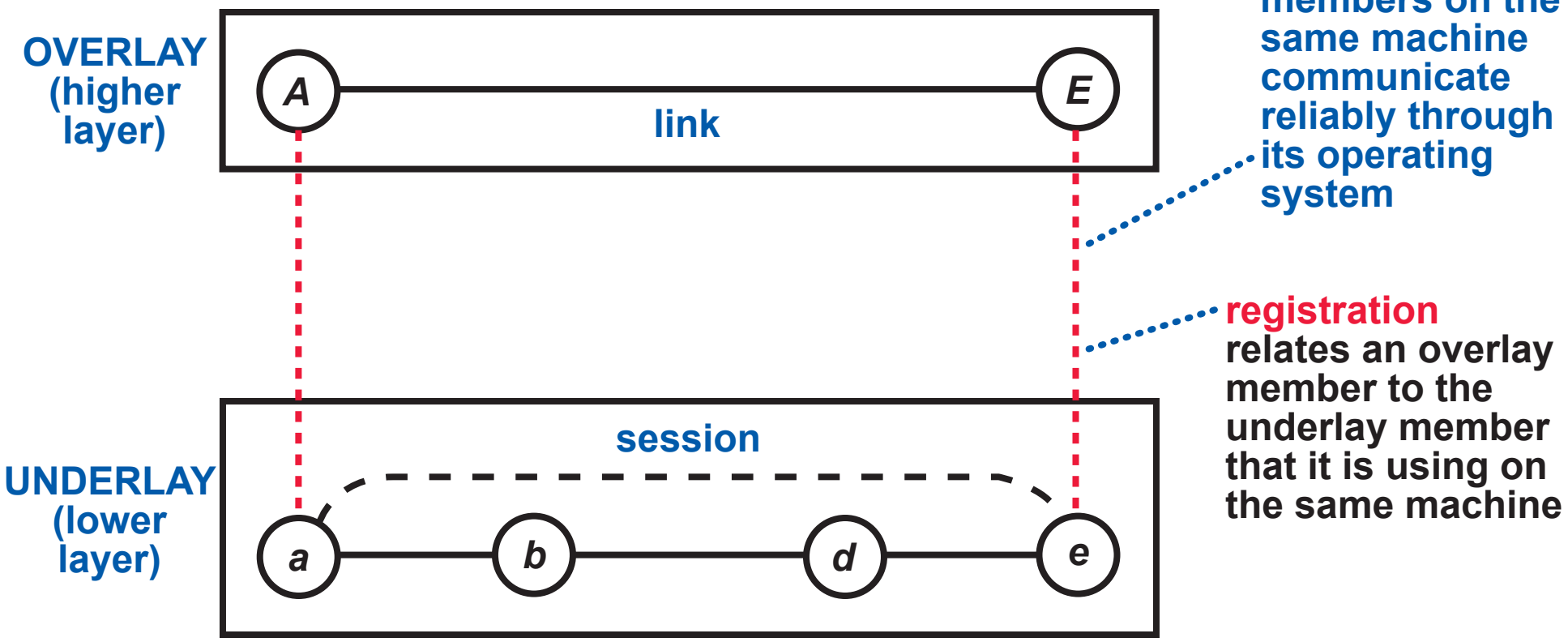


from the perspective of the endpoints, sessions are more convenient than links

may have . . . reliability,
. . . FIFO delivery,
. . . security,
. . . and other services

A NEW LAYER MODEL: THE "USES" HIERARCHY

when an overlay uses an underlay,
a link in the overlay is implemented
by a session in the underlay



possible setup of this link/session:

1. *A* sends request to *a*
2. *a* looks up registration of *E*, finds *e*
3. *a* sends request to *e*
4. *e* sends request to *E*

A NEW LAYER MODEL: MAJOR PARTS

PROTOCOLS

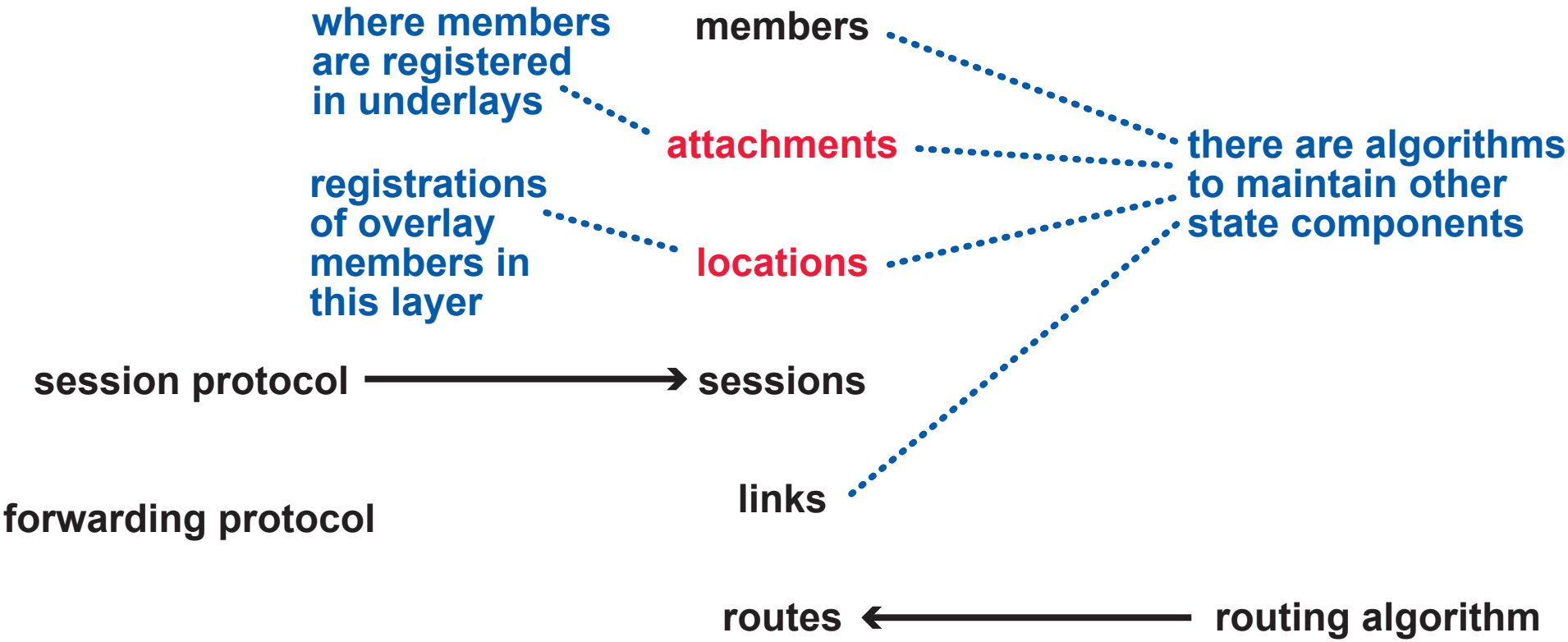
or, the "data plane"

STATE COMPONENTS

can be centralized or distributed across the members in any way

ALGORITHMS

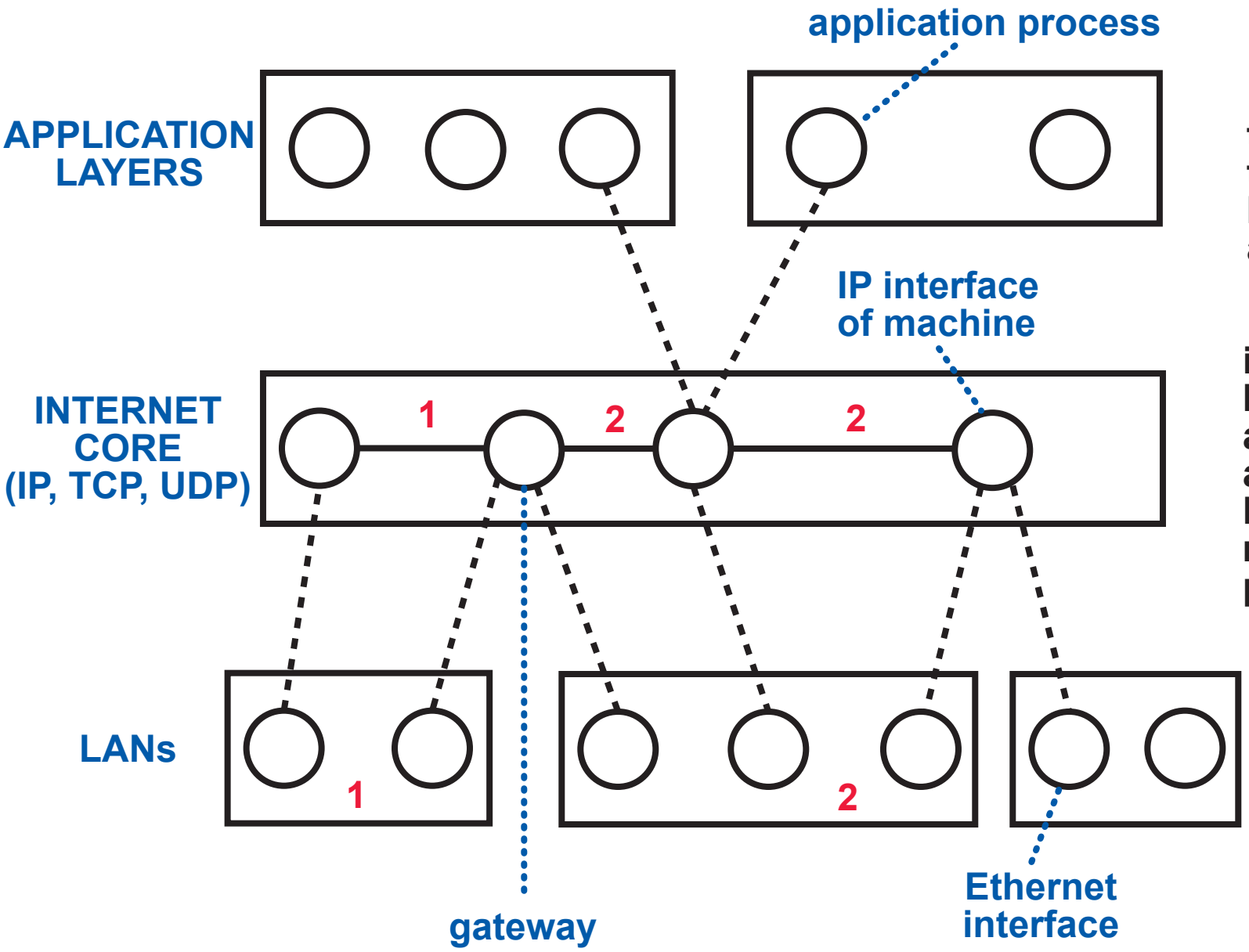
or, the "control plane"



A NEW LAYER MODEL: SCOPE AND LEVEL

layers are arranged in a "uses" hierarchy, which defines levels

the scope of a layer is the set or class of processes that could be members

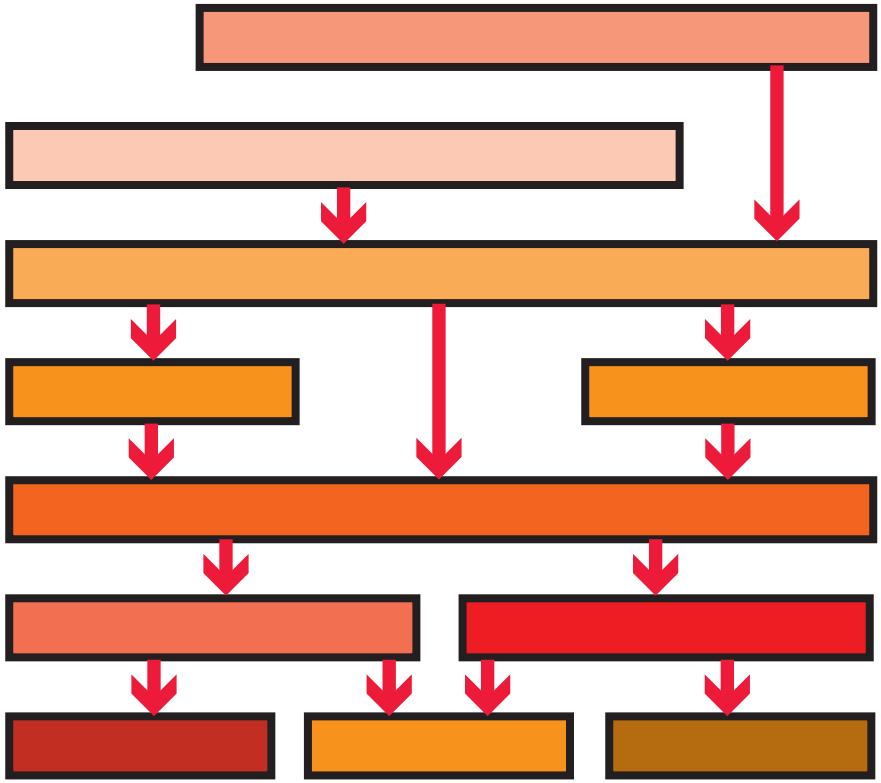


this describes the classic Internet architecture

in the real Internet, there are layers at many more levels, for many different purposes

WE CALL THIS THE "GEOMORPHIC VIEW" OF NETWORKING . . .

. . . BECAUSE THE COMPLEX ARRANGEMENT OF LAYERS RESEMBLES THE EARTH'S CRUST



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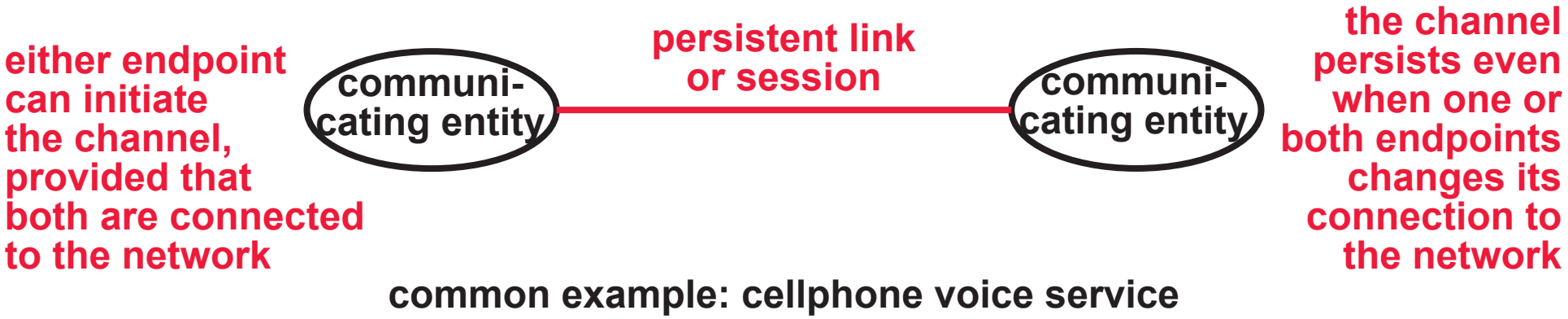
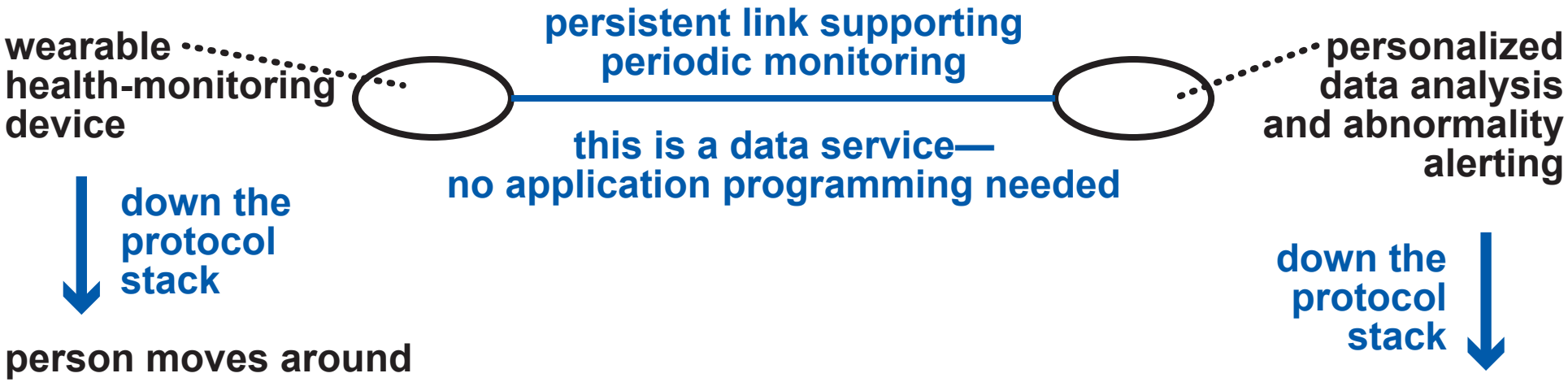
4 FUTURE WORK

A DEFINITION OF MOBILITY



common example: cellphone voice service



person moves around

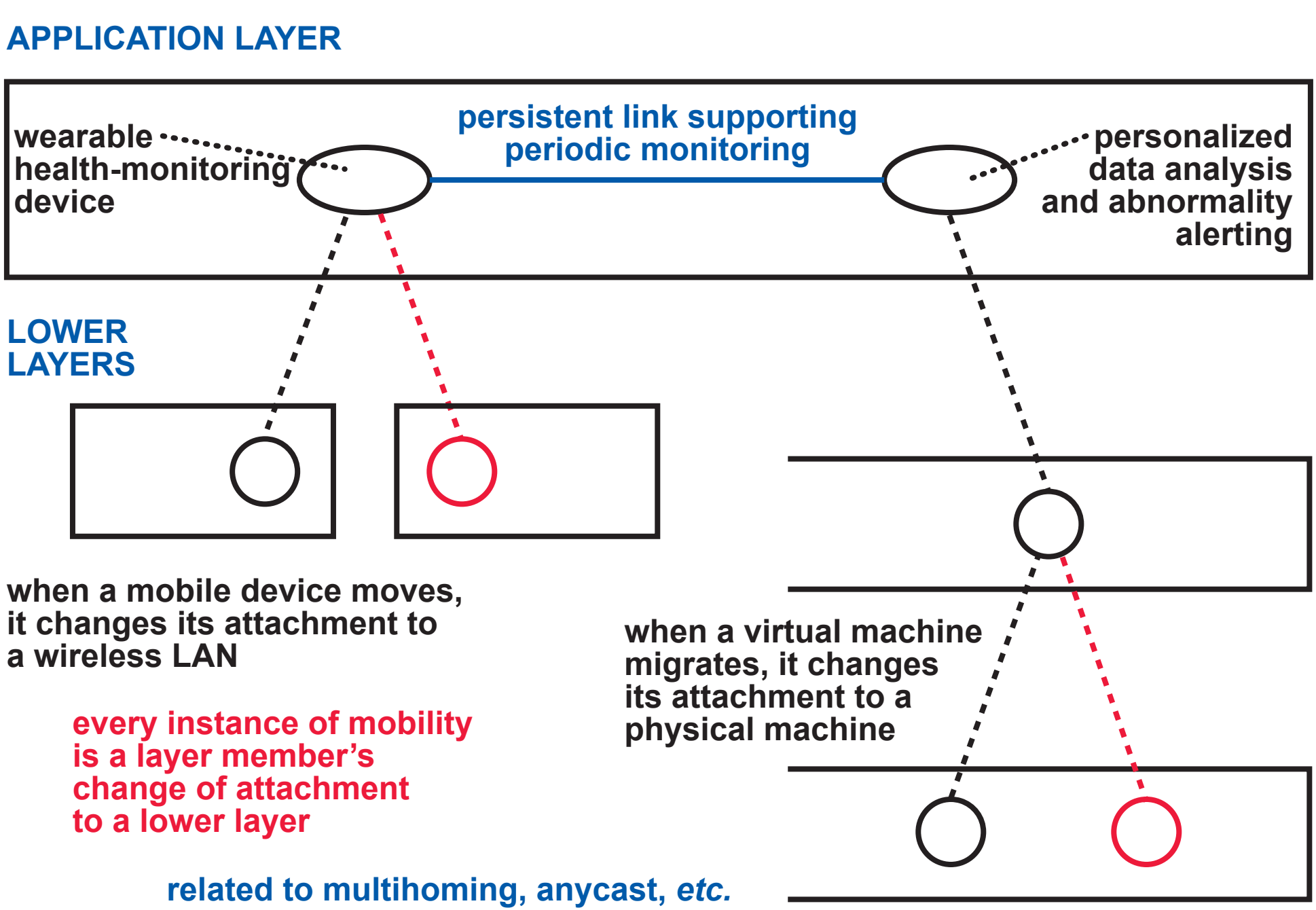
device uses both cellular and WiFi connections, alternatively or simultaneously

minimal keep-alive signaling, to reduce battery drain

virtual-machine migration

re-routing around failed links to data center

A DEFINITION OF MOBILITY, CONTINUED



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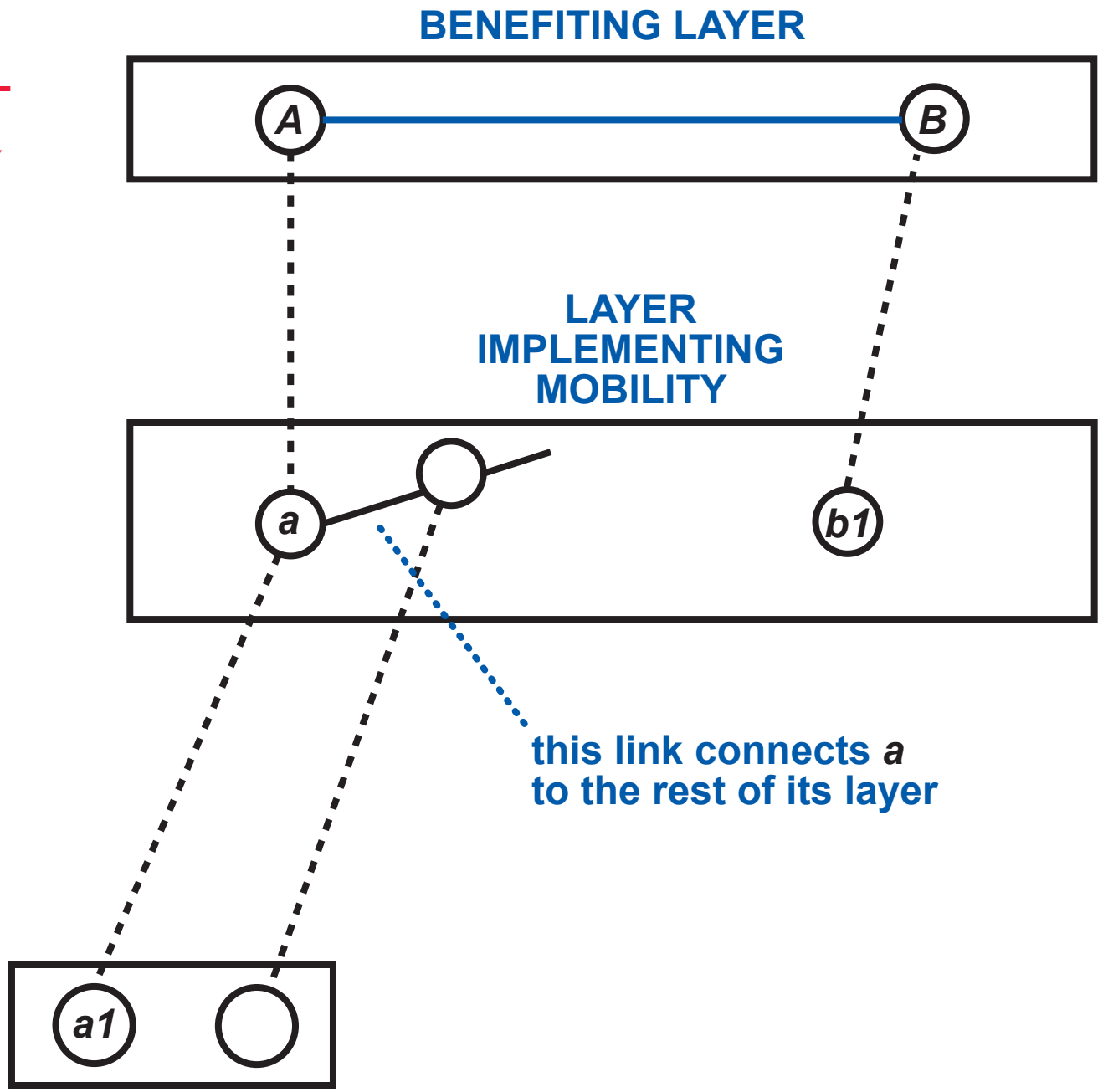
A PATTERN FOR IMPLEMENTING MOBILITY

DYNAMIC-ROUTING MOBILITY



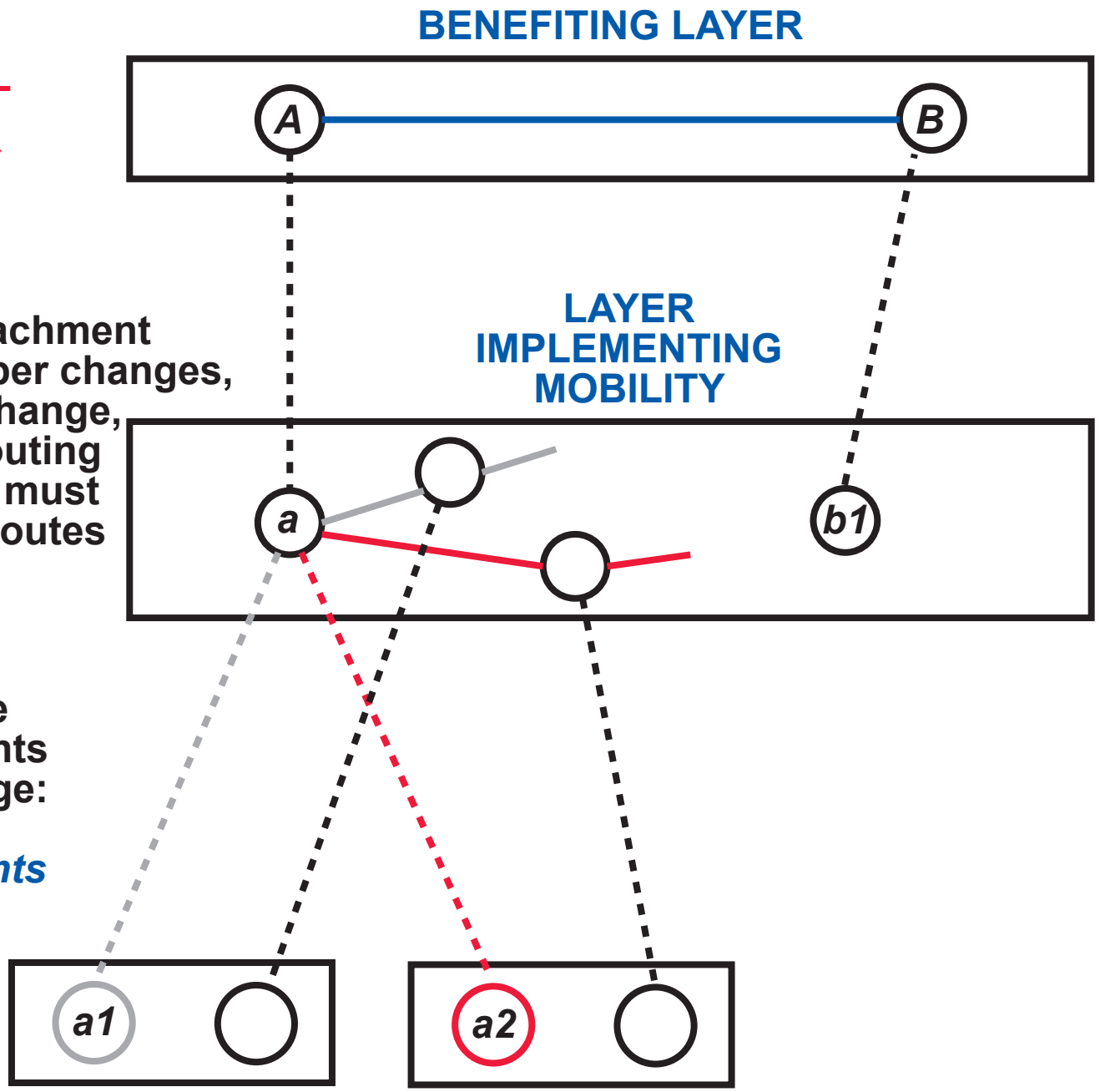
A PATTERN FOR IMPLEMENTING MOBILITY

DYNAMIC-ROUTING MOBILITY

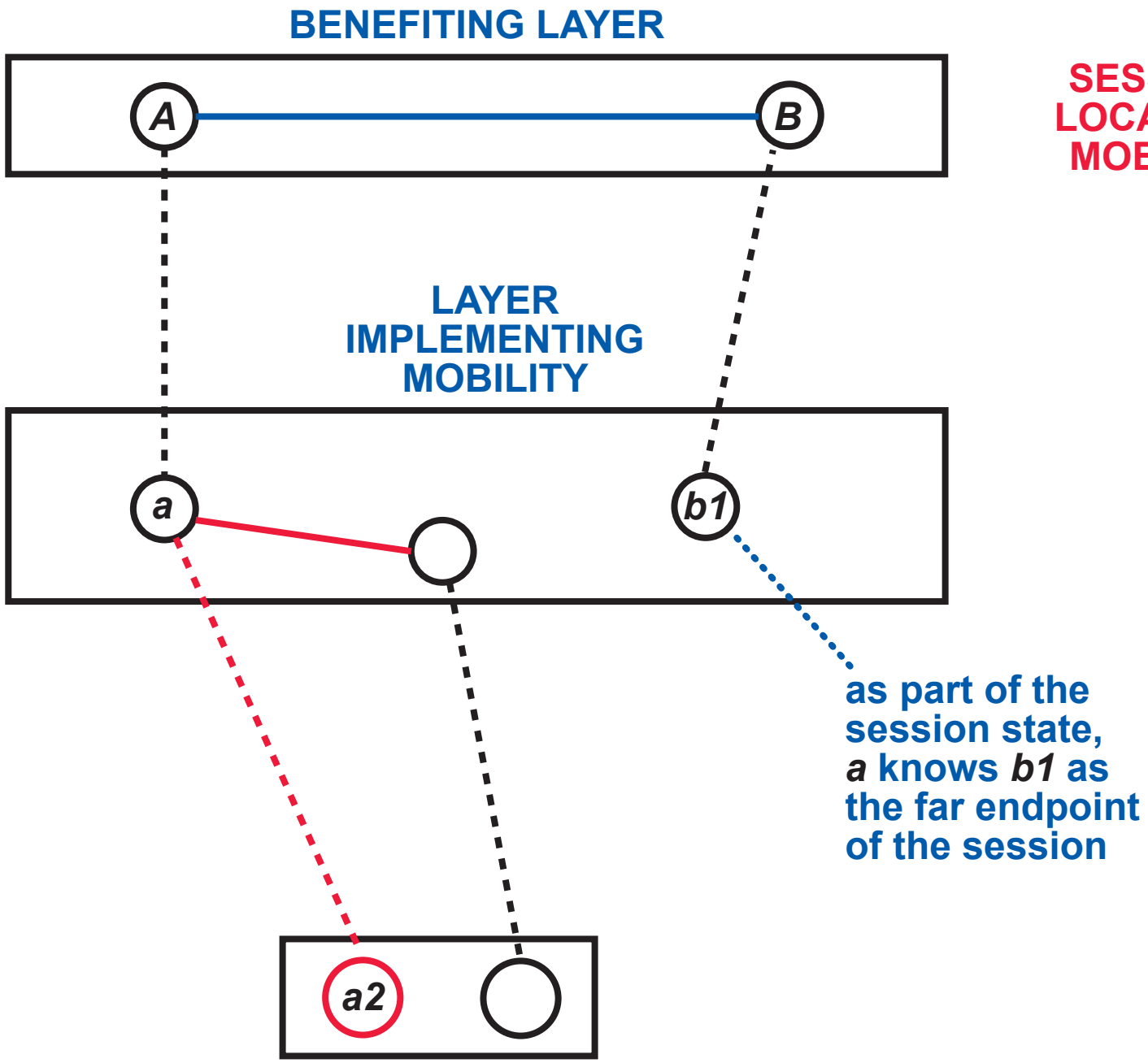
as the attachment of a member changes, its links change, and the routing algorithm must find new routes to it

layer state components that change:

attachments
links
routes



ANOTHER PATTERN FOR IMPLEMENTING MOBILITY



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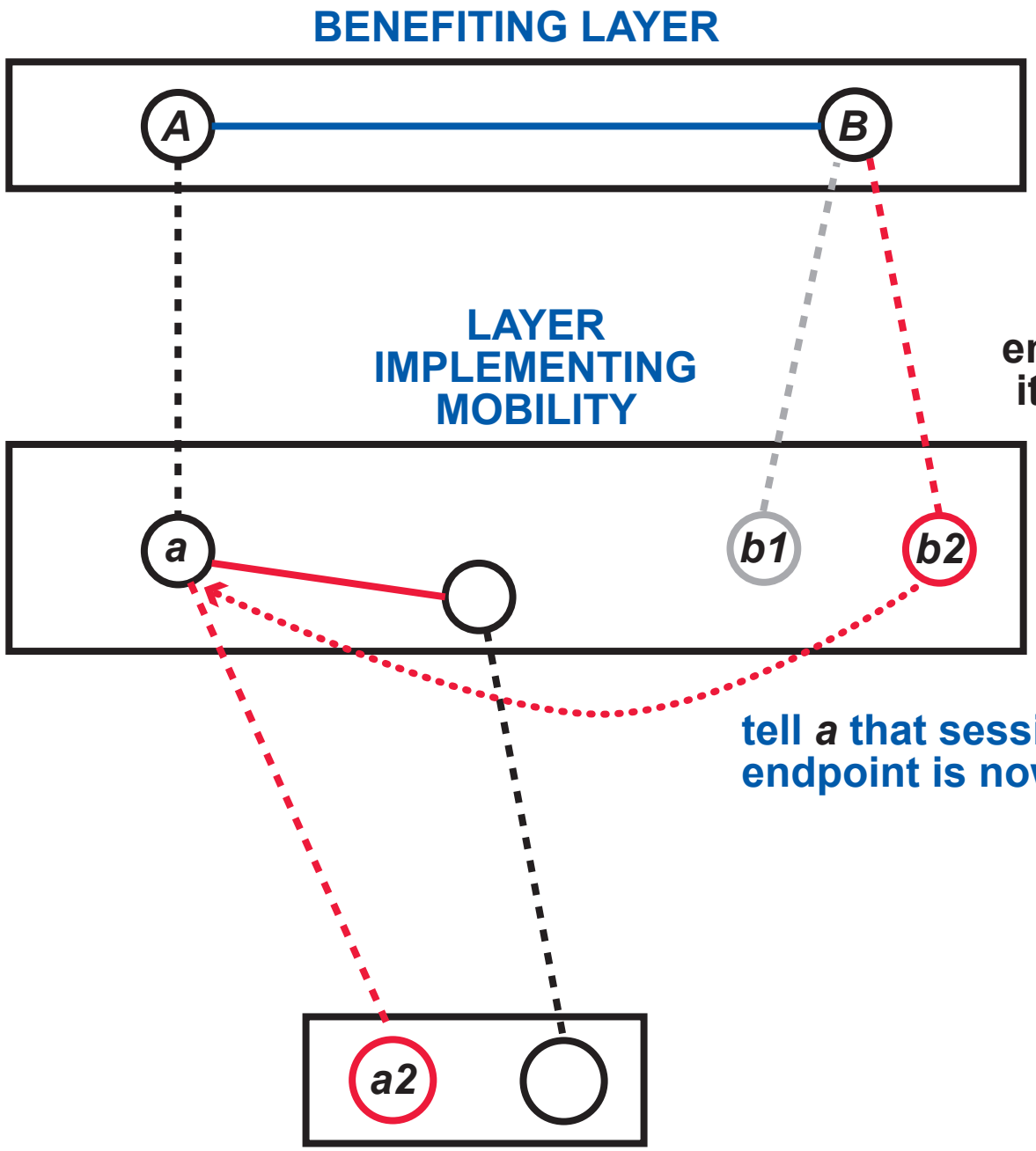


SESSION-LOCATION MOBILITY

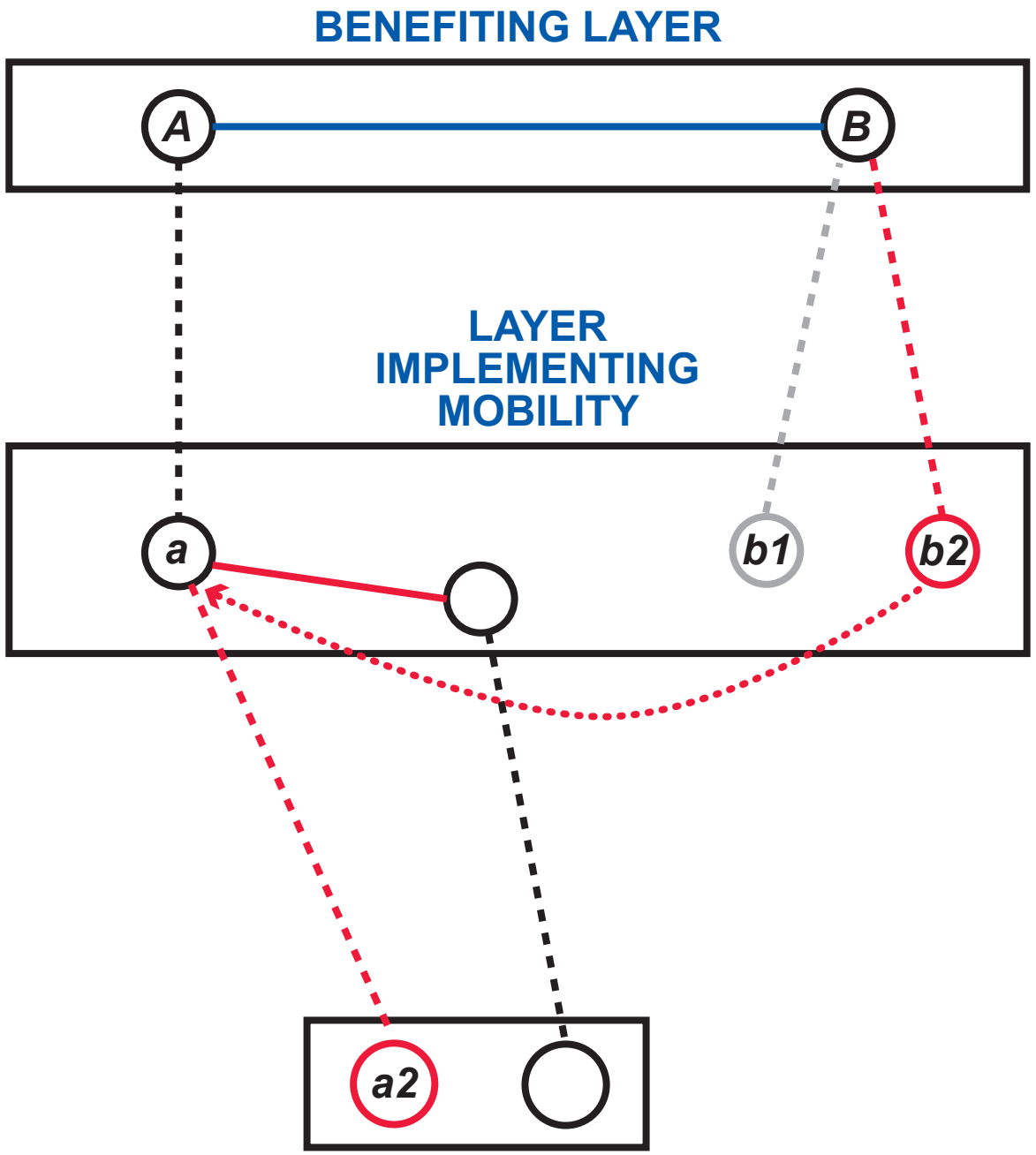
as the link endpoint changes its location in the implementing layer, the session state changes to match it

tell *a* that session endpoint is now *b2*

layer state components that change:

members
locations
sessions

BOTH PATTERNS FOR IMPLEMENTING MOBILITY



DYNAMIC-ROUTING MOBILITY

SESSION-LOCATION MOBILITY

layer state components that change:

attachments
links
routes

layer state components that change:

members
locations
sessions

STRENGTHS AND WEAKNESSES OF THE PATTERNS

see our chapter "*The design space of network mobility*"
in the new SIGCOMM eBook

DYNAMIC-ROUTING MOBILITY

Strengths

Works well in a layer with a smaller scope and a flat name space—usually dynamic routing for mobility is no different from "normal" routing.

e.g., Ethernet

Weaknesses

In a larger layer with a hierarchical name space, costs for dynamic routing to individual members are high.

How many routers know where to find a mobile member?

trade-off:
- if many, storage and update costs are high
- if few, path costs are high

e.g., Mobile IPv4

SESSION-LOCATION MOBILITY

Strengths

Low storage and update costs.

No path costs.

Weaknesses

Requires endpoint involvement, so cannot be deployed without changing endpoint software.

Message losses during handover may be disruptive.

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COMPOSITIONAL NETWORK MOBILITY

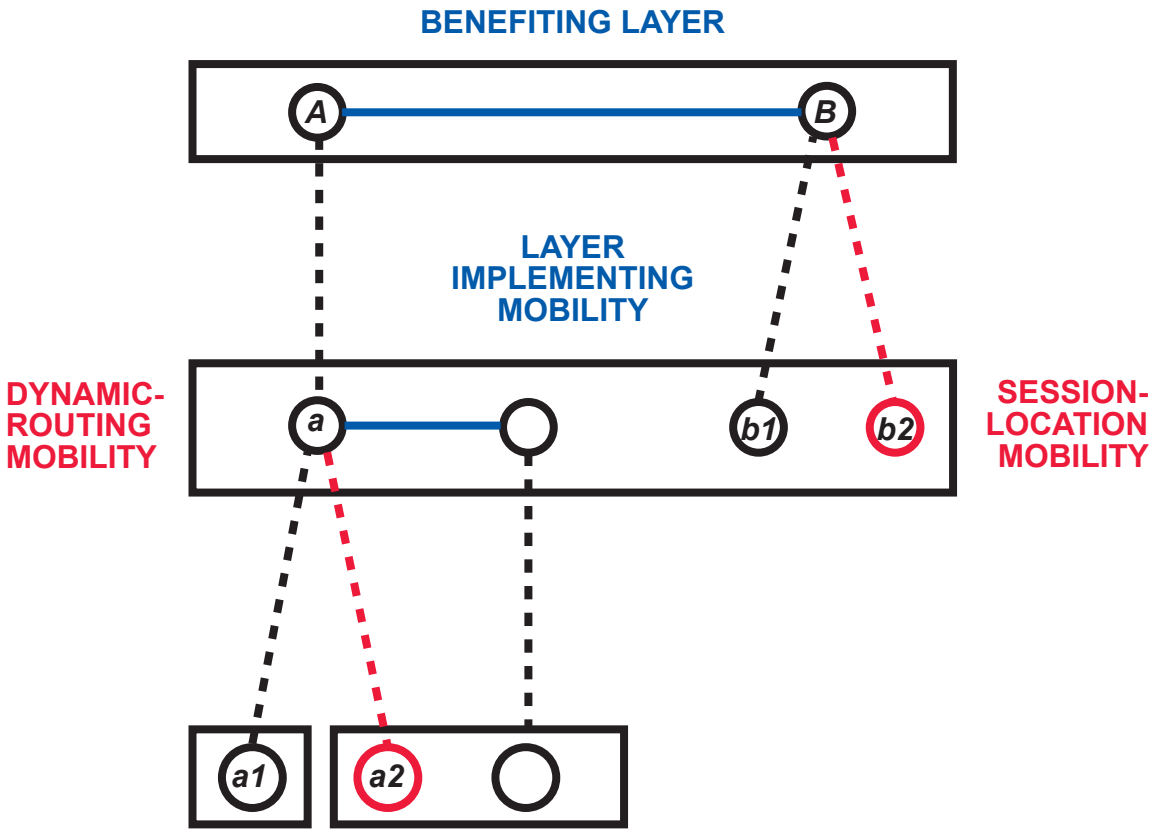
- every mobility mechanism specializes one of these patterns, or is a composition of the two

with enough design freedom, instances of mobility can be moved up and down the levels

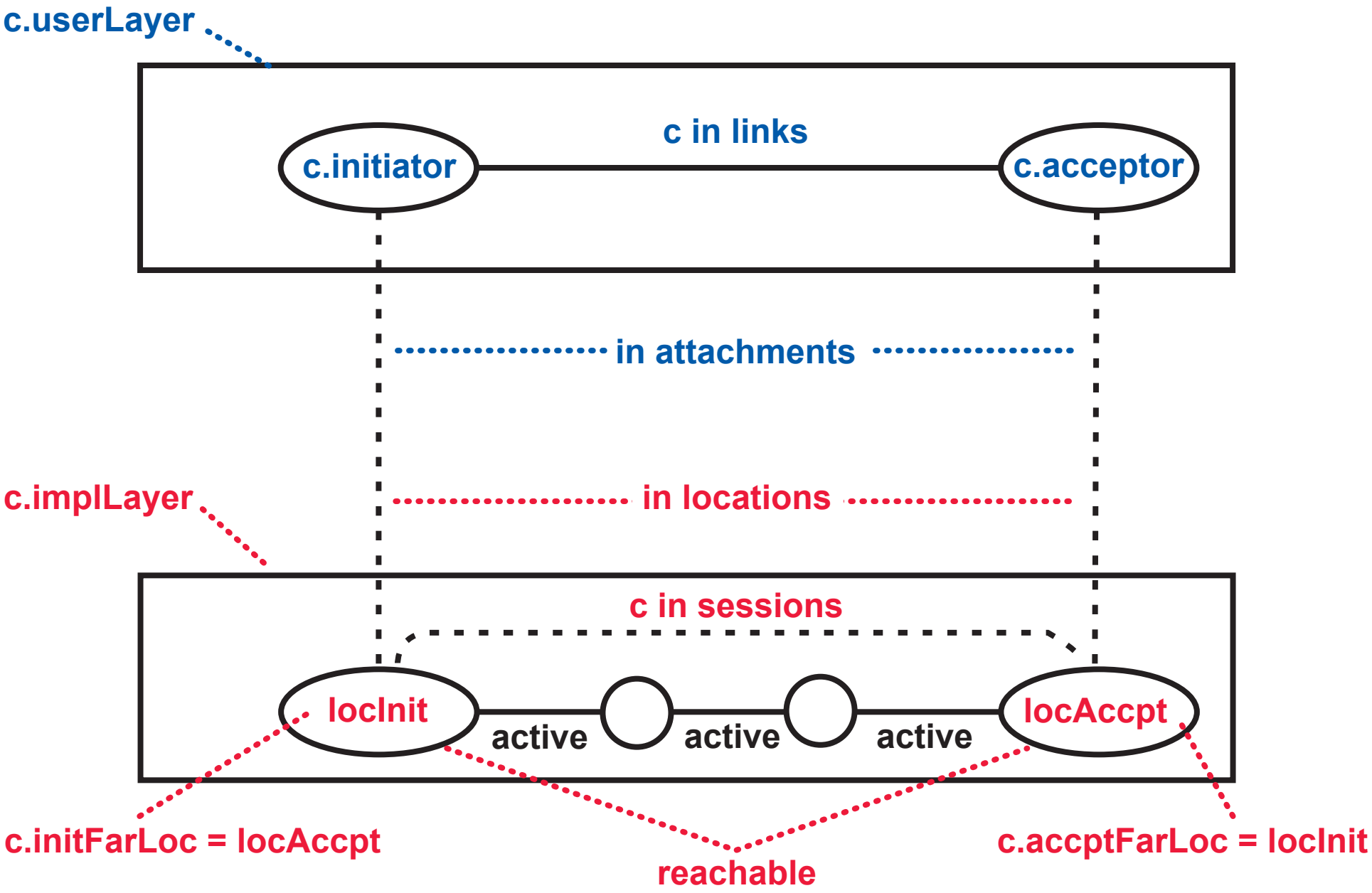
- in principle, each instance of mobility could be handled with either of these patterns at any level below the benefiting layer —so mobility mechanisms could be everywhere

there is a large design space, much of it unexplored

- an interesting question: how do implementations of both patterns in the same layer compose?

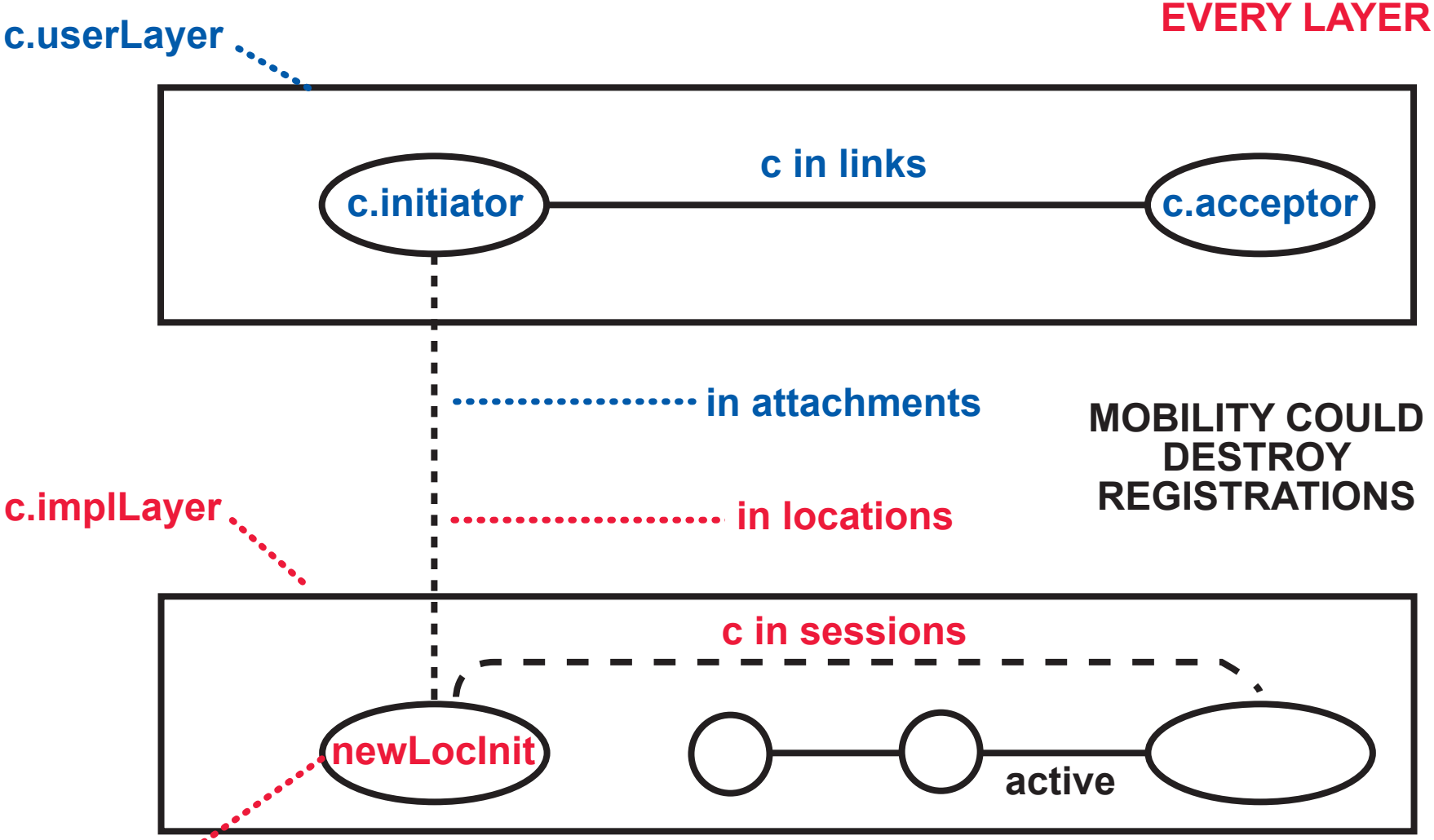


AN ACTIVE IMPLEMENTED CHANNEL



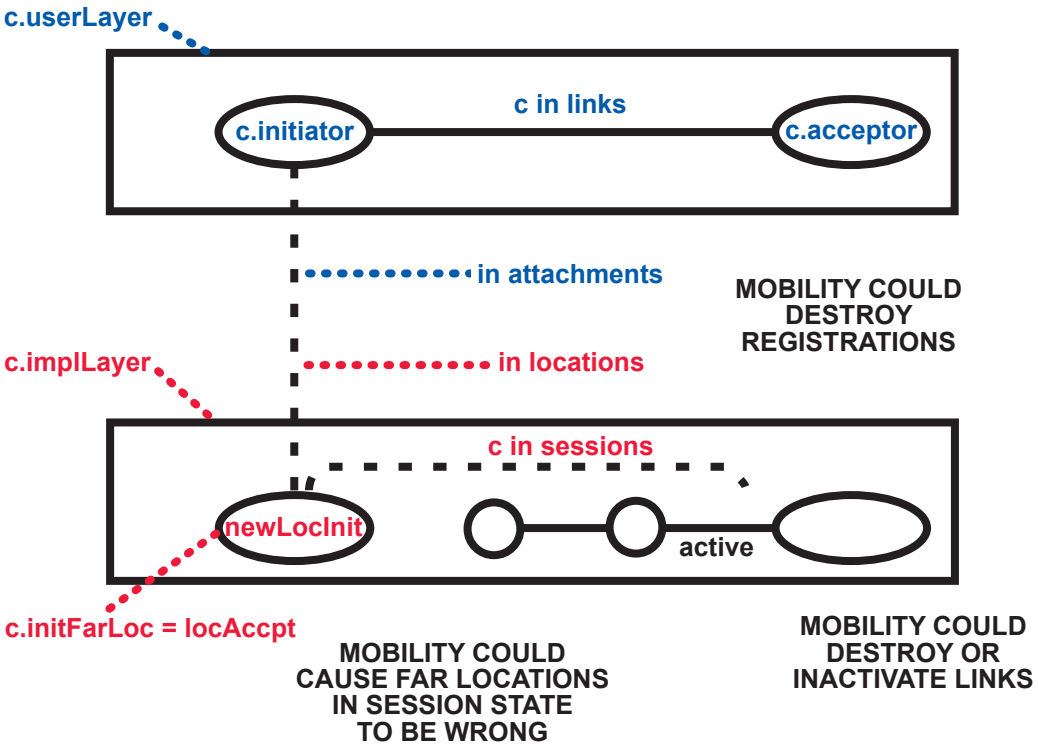
AN INACTIVE IMPLEMENTED CHANNEL

MODEL IMPLEMENTS BOTH PATTERNS IN EVERY LAYER



PROOF THAT MOBILITY MECHANISMS IN A LAYER COMPOSE WITHOUT INTERFERENCE

We cannot assume that mobile devices and network elements will perform all the requisite actions (to prove a true progress property).



We do assume that a mobile device can always become a member of a layer of its choice.

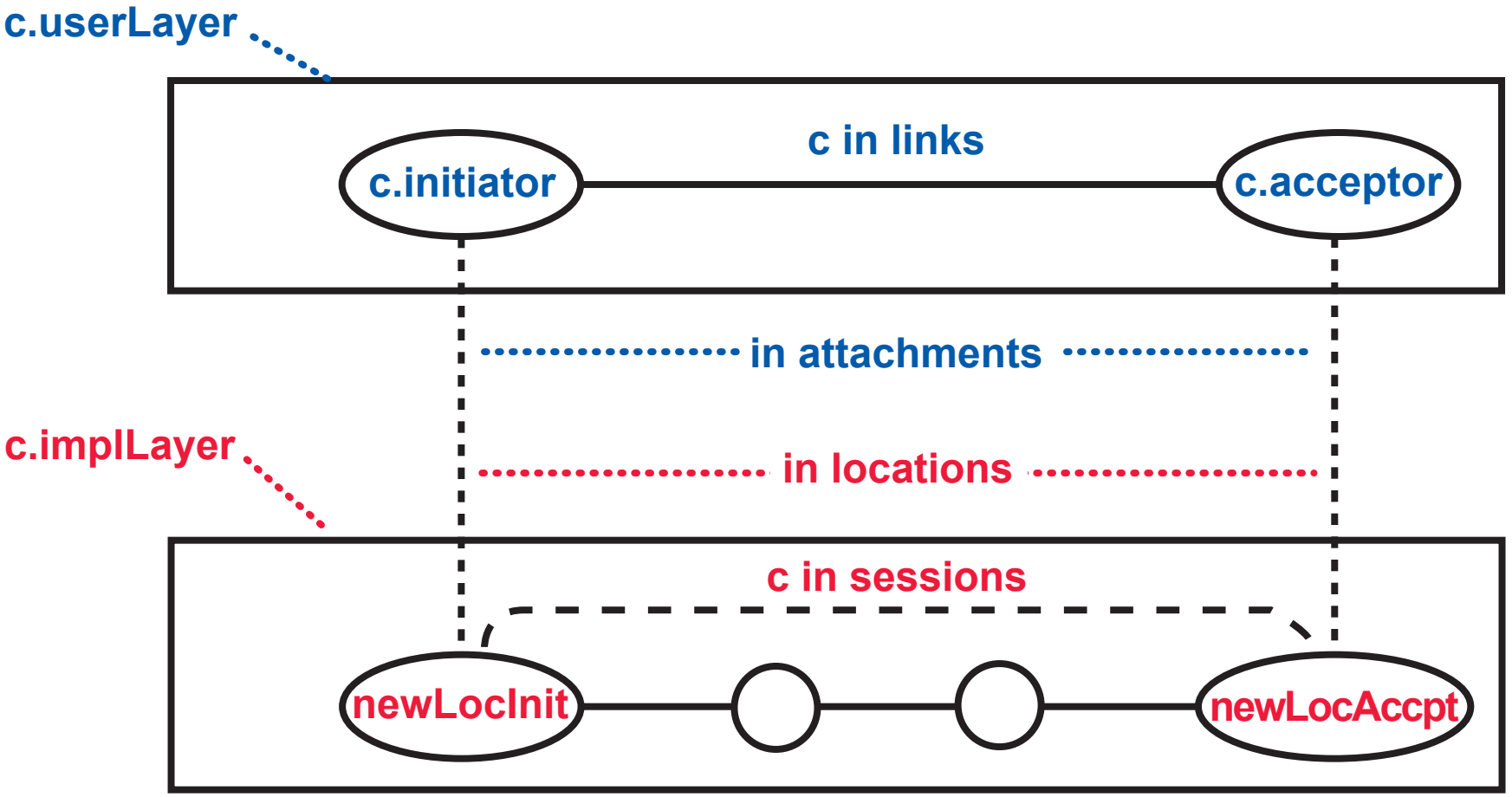
Theorem:

In any state in which an implemented link is inactive, some event is enabled whose execution will make progress toward making the link active (a safety property).

Proof at one level:

Manual enumeration of possible event sequences, automated checking of their preconditions with the Alloy Analyzer (verification over small domains).

WHAT COULD GO WRONG?



c.initFarLoc = locAccpt

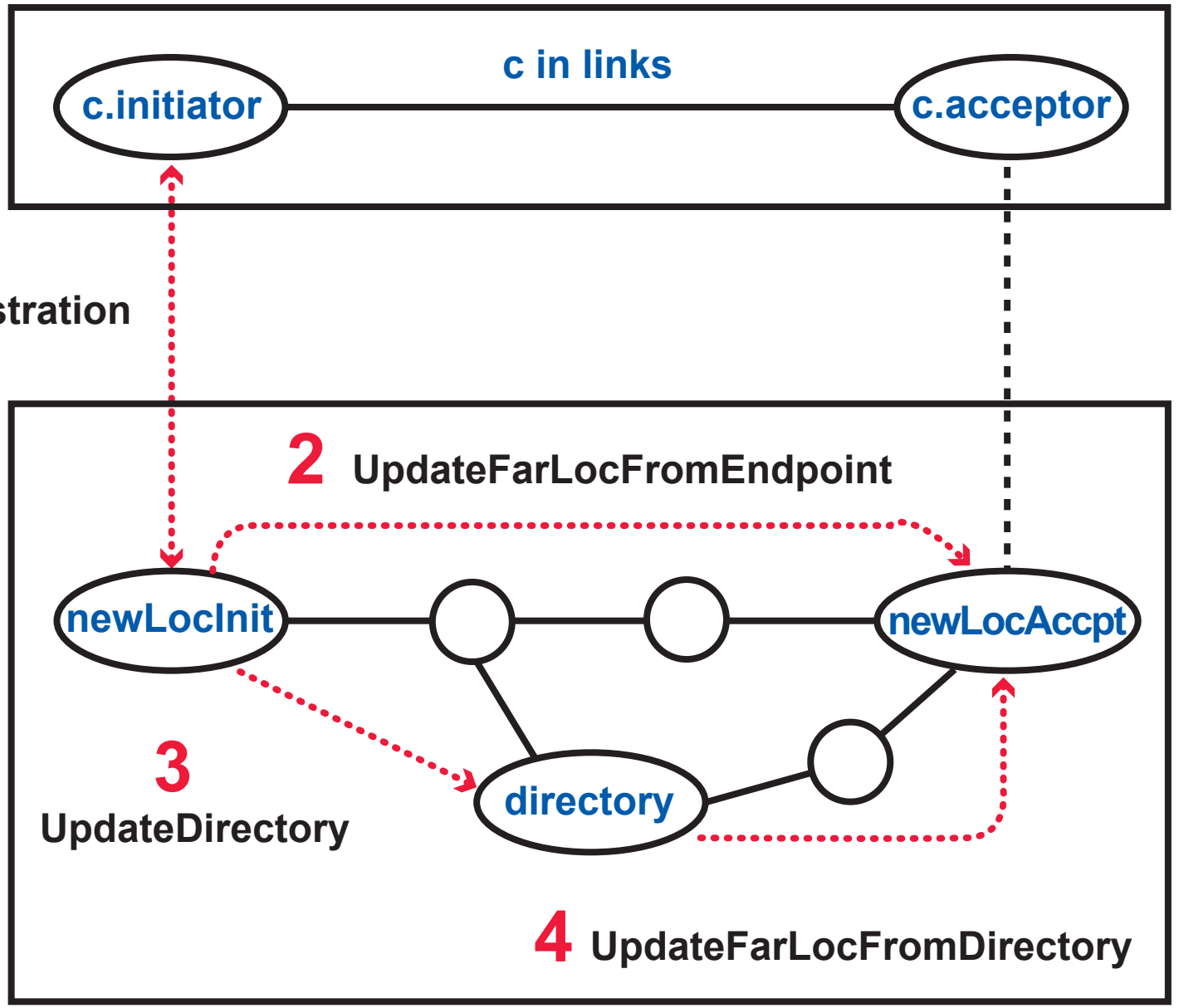
both endpoints have moved

c.accptFarLoc = locInit

both endpoints have the wrong far location

neither can send an update message to the other

SOME EVENT SEQUENCES



in the double-handoff scenario,

1, 2, 3 and 1, 3, 2

do not work, but

1, 3, 4 does

WHAT DOES THE THEOREM REALLY MEAN?

Events are coarse-grained and probably not implemented atomically.

In real network implementations, the problem is always conflation of concerns.

fields are overloaded,
existing mechanisms are "repurposed",
etc.

The theorem provides a set of constraints on independence of events and separation of data . . .

. . . that are *sufficient* to prove composability of the two patterns.

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EVALUATION OF STANDARDS FOR SESSION-LOCATION MOBILITY

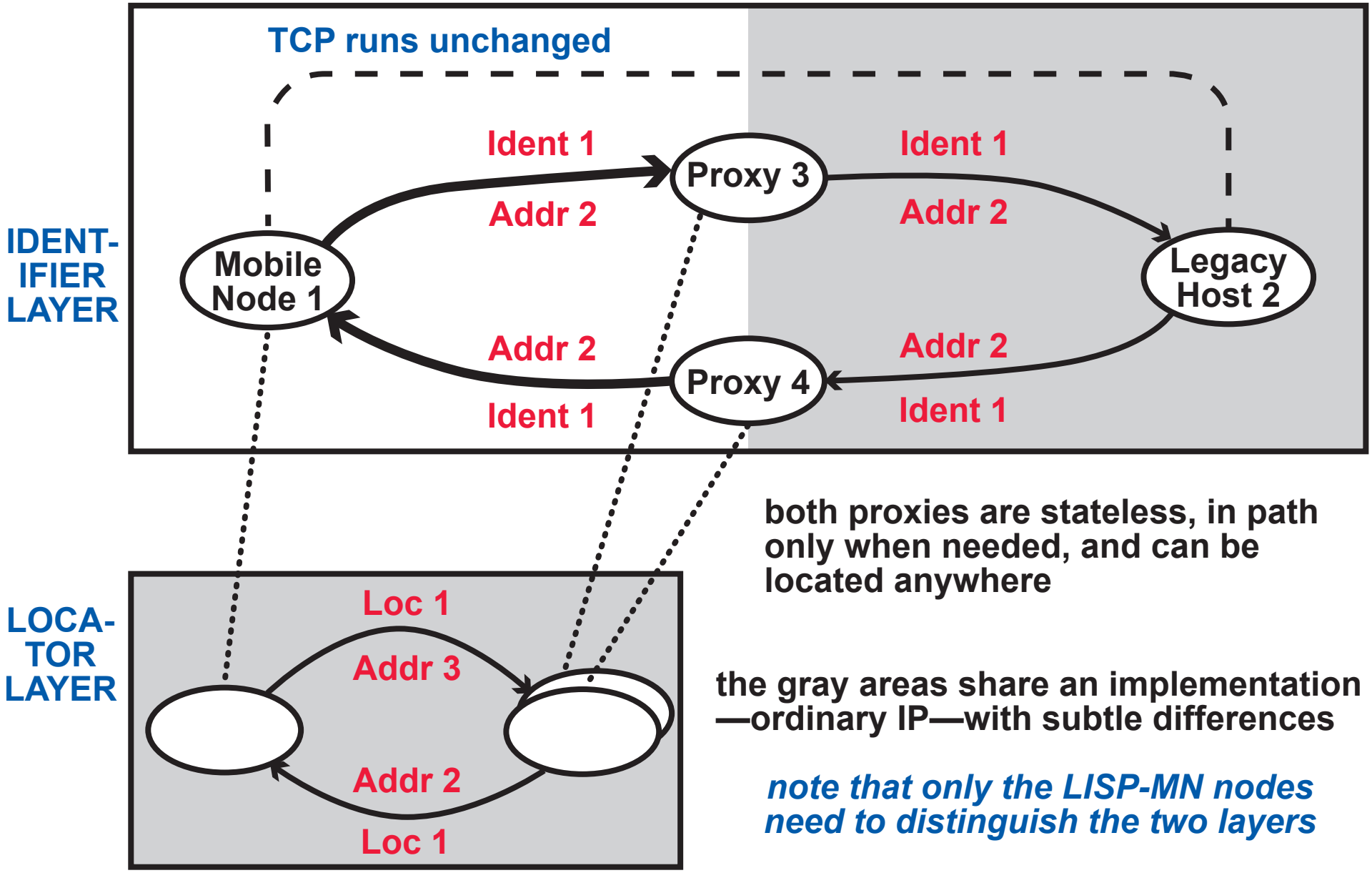
or, how to survive thousands of pages of IETF RFCs

It is a lot easier to read them when you have the pattern in mind and know what you are looking for!

STANDARDS	THEIR IDENTIFIERS
Mobile IPv6	*locators are always IP addresses, usually IPv6*
the "route optimization" mechanism, composed in a complex way with dynamic-routing mobility	
LISP Mobile Node	IP addresses
a useful afterthought to LISP, whose purpose is not mobility	
HIP	public keys, or hashes thereof
ILNP	64-bit suffixes of IPv6 addresses, where the locator is the whole address
IETF documents with "experimental" status	

STRUCTURAL COMPARISON ON INTEROPERATION

LISP Mobile Node is the best for interoperation, best overall



both proxies are stateless, in path only when needed, and can be located anywhere

the gray areas share an implementation —ordinary IP—with subtle differences

note that only the LISP-MN nodes need to distinguish the two layers

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THE DESIGN SPACE OF CLOUD COMPUTING

HOW CAN THE COMPOSITION OF ALL THESE REQUIREMENTS BE SATISFIED?

SERVICES FOR ENTERPRISE CUSTOMERS

- customizable address space
- services provided by proxies and middleboxes (especially security), with elastic resources
- broadcast domains

GUARANTEES FOR ENTERPRISE CUSTOMERS

- isolation
- quality of service

CLOUD MANAGEMENT

- virtual-machine migration
- multiple data centers
- fault tolerance

INTERESTING OBSERVATION:

Most requirements seem to have two implementations, . . .

. . . one in a routing algorithm, and

. . . one in a session protocol.

NETWORK VERIFICATION AND HEADER-SPACE ANALYSIS

FLATTENS ALL LAYERS INTO ONE SPACE WHERE COMPUTATION IS DEFINED

SOME AREAS OF DIFFICULTY:

- need to discover relevant packet fields and describe their transformations
- important assertions may only be expressible in layers above the base IP layer, or may cross layers
- the flattened space is large and computationally complex

THE GEOMORPHIC VIEW

ENCOURAGES AND ELUCIDATES SEPARATION OF LAYERS

HOW THE GEOMORPHIC VIEW MIGHT HELP:

these are easier to understand and formalize when layers are separated first

might allow analysis to be decomposed hierarchically