The Rise of the Middle and the Future of End to End

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In the Beginning…

- Saltzer, Reed, and Clark (circa 1988)
  - The function in question can completely and correctly be implemented only with the knowledge and help of the application standing at the end points of the communication system.
  - Therefore, providing that questioned function as a feature of the communication system itself is not possible.
  - Sometimes an incomplete version of the function provided by the communication system may be useful as a performance enhancement.
- Foundational principle of the Internet Architecture.
- The Internet's via negativa.

…In the Middle…

- Carpenter (RFC 1958, 1996):
  - An end-to-end protocol design should not rely on the maintenance of state (i.e. information about the state of the end-to-end communication) inside the network.
  - Such state should be maintained only in the endpoints, in such a way that the state can only be destroyed when the endpoint itself breaks (known as fate-sharing).
- The end to end principle applies to the entire network stack on the end node.
- The end to end principle specifies where to maintain "hard state".
  - Hard state: consequences of loss are catastrophic for the conversation between nodes.

Role of Soft State

- Again Carpenter (RFC 1958, 1996):
  - [Network] state must be self-healing; adaptive procedures or protocols must exist to derive and maintain that state, and change it when the topology or activity of the network changes.
  - The volume of this state must be minimized, and the loss of the state must not result in more than a temporary denial of service given that connectivity exists.
  - Manually configured state must be kept to an absolute minimum.

Pressures from the Bubble

- Not everybody using the Internet is honest or co-operative.
  - Fundamental lack of trust.
- Some interests want to provide new services as part of their base network access offering.
  - Example: content distribution in broadband networks for streaming audio.
- Most Internet users today are technically naïve.
  - And want their technical involvement to be the same as using a blender.

Preserving the Positive Consequences of End to End

- Preserve the ability for small inventors to develop and deploy innovative services easily.
- Maintain protection of robustness and reliability due to traditional network faults.
- Increase robustness and reliability in the face of subtly engineered attacks.
  - Protocols need to pay attention to the trust relationships between entities.
- Apply the end to end principle to each node to node conversation of a distributed application.

The Internet Standards as an Arena of Conflict

- Players in Internet standards often have conflicting interests.
- Conflicts will show up in the Internet architecture.
- Some conflicts can’t be resolved technically.
- Standards should be defined to align with conflict boundaries to minimize collateral damage.
- Standards should preserve core Internet values:
  - Reliability and integrity of end to end service.
  - Supporting trust and “good citizen” behavior.
  - Fostering innovation in network services.

Conclusion

- The end to end principle continues to be a vital inspiration for new engineering in the Internet.
- New pressures on the end to end principle can be accommodated by applying it to each node to node conversation.
- Broader context of end to end involves “good citizen” behavior emphasizing core Internet values.
- For more discussion:
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