Advanced Networking: Introduction

Geert Heijenk, Pieter-Tjerk de Boer, Roland van Rijswijk-Deij, Niels Overkamp, Cristian Hesselman

University of Twente | September 7, 2022
Advanced networking in 1989 :-)

https://computerhistory.org/blog/the-two-napkin-protocol/
Your teaching team

Geert Heijenk  
(teacher)

Pieter-Tjerk de Boer  
(teacher)

Roland van Rijswijk-Deij  
(teacher)

Niels Overkamp  
(teaching assistant)

Cristian Hesselman  
(teacher and coordinator)
Today’s learning objective

• Guide you through what we expect from you and why, and what you can expect from us

• Get you even more excited about internetworking :-) 

• Answer questions you may have on assessment, deliverables, etc.

• Full details on the ANET site at https://courses.sidnlabs.nl/anet/
Agenda

• High-level introduction to how the Internet works (and a bit of history)

• Course overview (admin talk)

• Short overview of the P4 lab assignment (Niels)

• Q&A

• Introduction of SIDN Labs (if time permits)
How the Internet works
(from a 50,000-foot perspective)
What is the Internet?
Wikipedia: networks of networks

- Internet: “the global system of interconnected computer networks that use the Internet protocol suite (TCP/IP) to link devices worldwide. It is a network of networks that consists of private, public, academic, business, and government networks of local to global scope, linked by a broad array of electronic, wireless, and optical networking technologies”

- Computer network: “a digital telecommunications network which allows nodes to share resources. In computer networks, computing devices exchange data with each other using connections between nodes (data links.) These data links are established over cable media such as wires or optic cables, or wireless media such as WiFi”
A set of properties or values

<table>
<thead>
<tr>
<th>Critical Property</th>
<th>Benefits</th>
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<tbody>
<tr>
<td>1. An Accessible Infrastructure with a Common Protocol that is open and has low barriers to entry</td>
<td>Unrestricted access and common protocols deliver global connectivity and encourage the network to grow. As more and more participants connect, the value of the Internet increases for everyone.</td>
</tr>
<tr>
<td>2. Open Architecture of Interoperable and Reusable Building Blocks based on open standards development processes voluntarily adopted by a user community</td>
<td>Open architecture creates common interoperable services, which deliver fast and permissionless innovation everywhere. The inclusive standardization process and demand-driven adoption ensures that useful changes are adopted, while unnecessary ones disappear.</td>
</tr>
<tr>
<td>3. Decentralized Management and a Single Distributed Routing System which is scalable and agile</td>
<td>Distributed routing delivers a resilient and adaptable network of autonomous networks, allowing for local optimizations while maintaining worldwide connectivity.</td>
</tr>
<tr>
<td>4. Common Global Identifiers which are unambiguous and universal</td>
<td>A common identifier set delivers consistent addressability and a coherent view of the entire network, without fragmentation or fractures.</td>
</tr>
<tr>
<td>5. A Technology Neutral, General-Purpose Network which is simple and adaptable</td>
<td>Generality delivers flexibility. The Internet continuously serves a diverse and constantly evolving community of users and applications. It does not require significant changes to support this dynamic environment.</td>
</tr>
</tbody>
</table>

Table 1: Abstract Architectural Criteria for Characterizing the Internet

<table>
<thead>
<tr>
<th>Network Engineering</th>
<th>Economic</th>
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</thead>
<tbody>
<tr>
<td>(1) layered architecture</td>
<td>(1) General Purpose Platform</td>
</tr>
<tr>
<td>(2) end-to-end packet connectivity</td>
<td>(2) Markets</td>
</tr>
<tr>
<td>(3) global address space</td>
<td>(3) Open Access</td>
</tr>
<tr>
<td>(4) interconnecting multiple ASes</td>
<td>(4) Permission-less Innovation</td>
</tr>
<tr>
<td>(5) global reach</td>
<td>(5) Decentralized, distributed ownership &amp; control</td>
</tr>
<tr>
<td>(6) inter-AS routing protocol</td>
<td></td>
</tr>
<tr>
<td>(7) shared set of standardized protocols</td>
<td></td>
</tr>
</tbody>
</table>


ISOC, “The Internet Way of Networking – Defining the critical properties of the Internet”, Sep 2020
Key concepts of inter-networking (1978)

A. What data do I need?

B. Which device on the net hosts it?

C. How do I get there from my device?

Names

Addresses

Data

Connection

Device

Network

Routes

J. Shosh, “Inter-Network Naming, Addressing, and Routing”, Internet Experiment Note #19, January 1978
Largest collaboration ever

“The Internet works because a lot of people cooperate to do things together”

Under the hood: protocols and services

Most people

Services

Names, addresses, routes, transports

Transmission

You and us
The complexity is huge

https://www.ietf.org/blog/herding-dns-camel/
Rate of change

Fast

Slow!

Fast
When did the Internet start?
First packet ever: Oct 29, 1969

IEEE MILESTONE IN ELECTRICAL ENGINEERING AND COMPUTING

Birthplace of the Internet, 1969

At 10:30 p.m., 29 October 1969, the first ARPANET message was sent from this UCLA site to the Stanford Research Institute. Based on packet switching and dynamic resource allocation, the sharing of information digitally from this first node of ARPANET launched the Internet revolution.

October 2009
The origins of TCP/IP's design

Birthplace of the Internet
UCLA, Sep 2017
Fast forward to 2022

https://www.cidr-report.org/as2.0/
Where can the Internet be improved?
TCP/IP lessons learned

• Thin waist enabled worldwide deployment
  • Simple network layer (IP+BGP), weak demands on underlying networks
  • Stateless, unreliable, unordered, best-effort delivery

• Additions investigated include:
  • Multipoint communications, in addition to point-to-point model
  • Security, which is an add-on instead of an integral part of the core protocols
  • Mobility management (movement between networks)
  • Restrict the impact of local incidents so they don’t have global effects (e.g., a CA compromise)
  • Path verification capabilities
Proposed changes in the literature

Type 1: functional
Put functions not in TCP/IP in the (TCP/IP) network

- SCION
- Responsible Internet
- RINA
- MobilityFirst
- XIA

Move functions

Inter-network

Type 2: design patterns
New generic structures for protocol stacks and/or (protocol) interfaces

- TROSTKI ("layer 3.5")
- RINA (layers)
- XIA (addresses)
- FII (interfaces)

Add functions

Inter-network

Data-centric
Service-centric
XIA, FII (future concepts)
ManyNets

Comms concept

Inter-network

Type 3: comms concepts
Network provides other comms abstraction than TCP/IP's host-based model

Services

Comms concept

Services
Example: the Responsible Internet

• Addresses lack of insight in and control over Internet’s end-to-end structure and operation

• Tree new **design goals**: controllability, accountability, and transparency (CAT)

• Hypothesis: enables relying parties to communicate with more confidence and trust
  • Critical service providers
  • Policy makers
  • Network operators
  • Individuals
Summary

• Relatively simple design of the Internet’s core protocols solved problem of ubiquitous connectivity, Internet now critical for almost every aspect of our everyday life and for our society

• Challenge: how to align the Internet’s services with society’s increased demands?
  • Higher levels of trust and autonomy to support new safety-critical applications
  • New network functions (e.g., security, privacy, real-time guarantees)
  • New (open programmable) internet designs

• We expect that some of these extensions and designs will have an impact on deployed network infrastructure in the next few years and ANET will help you navigate that space
Course overview

Details at https://courses.sidnlabs.nl/anet-2022/
ANET is an overview course based on research papers. It complements Internet Security, which goes more into depth on the security of specific Internet protocols.
Learning goals

• After successful completion of the course Advanced Networking (ANET) you will be able to:
  • Analyze, compare, and discuss various **advanced Internet concepts**, such as secure inter-domain routing and multi-path data delivery
  • Understand and discuss important **challenges and proposed experimental solutions**, including non-IP-based internetworking systems
  • Apply a domain-specific language such as **P4** to implement basic data plane functionality of an open programmable router, which is important for future Internet infrastructures
  • Enhance your research skills because you’ll need to independently review and analyze research papers and RFCs
Prerequisites

• Introductory course on computer networks

• Such as the bachelor module Network Systems at the University of Twente
Staying up to date

• ANET public homepage
  • https://courses.sidnlabs.nl/anet/
  • Authoritative source: papers, assessment, deliverables, etc.
  • Public site so other teachers/universities can potentially learn from our format

• ANET Canvas site
  • Announcements and comms with teachers
  • Uploading and archiving deliverables
ANET is a collaboration with SIDN Labs

• Motivation for SIDN Labs
  • Proud to help educating the next generation of Internet (security) engineers and researchers
  • Aligns with our research on secure future Internet infrastructures ([www.2stic.nl](http://www.2stic.nl))
  • Perhaps interest some of you to check out our work for an M.Sc. project 😊

• Extends ongoing academic-industry research collaboration
  • SIDN Labs: improve security and resilience of SIDN’s services and wider Internet using latest academic insights, methodologies, network, and creative thinking
  • UT: further improved research and education using SIDN’s operational experience, unique datasets, and industry network
Lectures

https://courses.sidnlabs.nl/anet-2022/#schedule
Regular lectures

• Eight interactive technical lectures
  • Protocols and Internet architectures/deployments
  • Motivation: enhance your “networking horizon”

• Each lecture revolves around a specific theme
  • Topics cover core functions of inter-domain networking (e.g., naming, routing, security)
  • Motivation #1: give you a broad overview of advanced networking functions
  • Motivation #2: our research interests (we love to talk about the work we do :-)

• Attendance is mandatory because of group tests and discussions (see next slides)
Themes

• “Going up the stack”: programmable networks (hardware), BGP security, DNS security and privacy, multi-path communication, QUIC, data center networking, Internet architectures

• Papers cover almost a quarter of a century of networking research, with the oldest one from the Internet’s proverbial “stone age” (1995)

• Help you understand generic network architectures and principles, not so much latest and greatest topics

• Additional reading on the ANET site
One theme per lecture

• One **introductory paper**
  • Tested through a closed book multiple-choice test in class
  • First do the test individually, then the same test in a group with 2-3 of your fellow students
  • Group test enables you to learn from your peers by discussing the test’s questions

• Two **advanced papers** that explore the topic in more depth
  • Tested through a blog and a presentation
  • One or two presentations per lecture, schedule on the ANET site

• We’ll publish the **best blog** on the ANET website (with the author’s consent)
### Timetable (yes, micromanagement)

<table>
<thead>
<tr>
<th>Time</th>
<th>What</th>
</tr>
</thead>
<tbody>
<tr>
<td>10:45</td>
<td>Arrival, put your cell phone in your bag, pick up hardcopy of tests at teacher’s desk, sit down</td>
</tr>
</tbody>
</table>
| 10:45-10:55 | Individual test of introductory paper  
Teacher will pick up the tests when everyone is done                           |
| 10:55-11:00 | Organize into groups (teacher divides you across groups)  
Teacher will pick up the tests when everyone is done                            |
| 11:00-11:10 | Group test of introductory paper (closed book)  
Teacher will pick up the tests when everyone is done                             |
| 11:10-11:30 | Discussion of the paper                                                                                                           |
| 11:30-11:45 | Break                                                                                                                            |
| 11:45-12:00 | Presentation #1 (10 minutes presentation, 5 minutes Q&A)                                                                         |
| 12:00-12:15 | Presentation #2 (10 minutes presentation, 5 minutes Q&A)                                                                         |
| 12:15-12:30 | Discussion of the two papers                                                                                                       |
| 12:30 | Adjourn                                                                                                                          |
Guest lectures

• Goal: give you a flavor of operational network infrastructure and current research

• Fri Oct 7: Prof. Cristel Pelsser of Uni Louvain (BE) on routing research (date TBC)

• Mon Oct 17: Ralph Koning and Caspar Schutijser (SIDN Labs) on SCION-in-P4 and SCIONlab

• Open to everyone
P4 lab exercises

• One extended intro, two on-campus lab sessions

• Making the lab exercises at home is fine, but you’ll need to come to campus to sign them off

• Lab sessions run by Niels (student assistant)

• More details in his talk :-)
Your deliverables
Overview

1. A total of 8 **multiple-choice tests** on introductory papers

2. A **blog** in which you review one of the advanced papers

3. A **presentation** of 15 minutes about that paper at one of the lectures

4. Lab **exercises** about programing for a P4-enabled router
Deliverable #1: multiple choice tests

• One individual tests per lecture: assess your understanding of the introductory paper

• One group test: do the individual test once more, but in groups (group-based learning)

• One topic per lecture (e.g., BGP security)

• Not tested: 20 min open discussion at the end of each lecture

• Grade = maximum of \( ((S-G)/(Q-G))*9+1 \) and 1

Make sure to browse a few of the ANET papers this week to double-check that ANET matches your interests, study plan, prerequisites, etc.
Deliverable #2: blog

• 1.500 words tops

• The blog must be self-contained and capture the essence of the paper

• Your target audience are readers with a background in computer networking

• Goal: readers should be able assess if they'd like to read the full paper based on your blog

• Examples of blogs on the ANET site

• Writing a good blog takes time!
## Example topics

<table>
<thead>
<tr>
<th>Design paper (e.g., [SCION])</th>
<th>Measurement paper (e.g., [DNS-SP])</th>
</tr>
</thead>
<tbody>
<tr>
<td>• What is the problem that the authors aim to solve?</td>
<td>• What is the problem that the authors aim to solve?</td>
</tr>
<tr>
<td>• What requirements do the authors articulate for their work?</td>
<td>• What methodology and experimental setup do the authors use?</td>
</tr>
<tr>
<td>• What does the high-level design and operation of their proposed system look like?</td>
<td>• What are their key findings and conclusions?</td>
</tr>
<tr>
<td>• How does the design address the requirements?</td>
<td>• How do they propose others use their measurement study?</td>
</tr>
<tr>
<td>• What are the pros and cons of the authors’ work and why?</td>
<td>• What are the pros and cons of the authors’ work and why?</td>
</tr>
<tr>
<td>• What would you do differently?</td>
<td>• What would you do differently?</td>
</tr>
<tr>
<td>• Would you recommend the paper to interested readers?</td>
<td>• Would you recommend the paper to interested readers?</td>
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</table>
Write the blog in your own words

<table>
<thead>
<tr>
<th>Style</th>
<th>Example</th>
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<tbody>
<tr>
<td>Citing</td>
<td>✔️ In our lab experiment, we use Manufacturer Usage Descriptions (MUDs) [RFC8250] to describe the network behavior of IoT devices.</td>
</tr>
<tr>
<td>Quoting</td>
<td>✔️ MUD was designed to “provide a means for end devices to signal to the network what sort of access and network functionality they require to properly function” [RFC8250]</td>
</tr>
<tr>
<td>Copying</td>
<td>❌ MUD was designed to provide a means for end devices to signal to the network what sort of access and network functionality they require to properly function [RFC8250]</td>
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- Also cite and quote sources where you are a co-author, if applicable

- As per the university’s policy, no forms of plagiarism are tolerated (check through Canvas)
Who writes about which paper?

- Indicate your ranked top 5 (1st, 2nd, 3rd, etc.) through Canvas by **Fri Sep 9, 2022**

<table>
<thead>
<tr>
<th>First name</th>
<th>Blogs about</th>
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Grading of your blog

• We will evaluate your blog based on the following criteria:
  • Understanding: how well did you understand the paper, for instance in terms of the problem it aims to solve and the paper’s key points?
  • Analysis: to what extent did you provide a critical analysis of the paper, for instance in terms of the pros/cons of the work, limitations of the proposed solution/approach, and potential improvements?
  • Clarity: structure, language, and readability of the blog

• The ANET teacher who gives a particular lecture will evaluate the blogs of that lecture
  • In addition, one of the other teachers will review your blog for a cross-check
  • They both use the evaluation criteria listed above to grade your blog
Deliverable #3: presentation

- Present your blog to your peers in at most 15 minutes, including 5 minutes of Q&A

- Teachers will score based on clarity, structure, and how well you responded to questions

- Your fellow students will do the same through a feedback form that we’ll hand out

- Pointers on how to make a presentation are on the ANET website
Deliverable #4: P4 lab assignment (1/2)

• Goal: learn how to program the packet handling functions of a simulated router using the domain-specific language P4

• Carry out the P4 assignment individually during the two lab sessions or at home

• Teaching Assistant (Niels) signs off at one of the two lab sessions

• Key requirements you’ll need to fulfil to get your P4 assignments signed off are:
  • Your P4 code needs to run and shows the expected behavior
  • You’re able to explain the Teaching Assistant what’s going on and why
  • You added comments to your P4 code explaining what you did and why
Deliverable #4: P4 lab assignment (2/2)

• We’ll have a paper on P4 in the second lecture

• Niels will provide a short lab intro after my talk

• Extended introduction on Wed Sep 21
Assessment

• Goal: evaluate to what extent you attained ANET’s learning goals

• Pass if \( (((\text{average score of your 8 individual tests}) \times 25\%) + (\text{average score of your 8 group tests}) \times 25\%) + (\text{score of your blog}) \times 40\%) + (\text{score of your presentation}) \times 10\%) \times (\text{score of your lab assignment}) \geq 5.5 \)

• The scores of the tests, blog, and presentation are between 1 (worst) and 10 (best)

• The score of the lab assignment is either 1 (pass) or 0 (fail)
Important dates

• Ranked top five of papers you’d like to blog about (1st, 2nd, etc.): **Fri Sep 9, 2022**

• Individual and group test: **at each lecture**

• Blog and presentation: **one week after the lecture** in which you presented the paper

• Lab assignment: **at the two lab sessions** (see ANET schedule)
Plan ahead!

• You need to deliver every week

• Writing a good blog and making a presentation takes time!

“I love deadlines. I love the whooshing noise they make as they go by.”
-- Douglas Adams
Change log
Class of 2021/2022 feedback (summary)

😀 Course format: group learning, individual blog writing, weekly exams, and practical sessions

😀 Topics and quality of the selected papers. Helped improving paper reading ability.

😀 Please include more (extended) P4 exercises

😐 Please highlight the key parts of the longer papers to reduce amount of reading

😐 Please be clearer about the requirements for the blog and when it’s due

8.4

#proud
Changes based on feedback class of 2021/2022

• Changed deadline for the blog to one week after the presentation

• Provided more guidance for writing the blog (design vs. measurement paper)

• Updated list of papers: [DCN2], [ICING], and [TUSSLE]

• Added a P4 exercise
P4 lab assignment

Niels Overkamp

University of Twente | September 7, 2022
To what extent do you understand what we expect from you and why, and what you can expect from us?
Got even more excited about inter-domain networking? 👍✊👎
# Advanced Networking (ANET)

**EC** 5 (140 hours)

**Prerequisites** Introductory course in computer networking, such as the bachelor module Network Systems at the UT

**Coordinator** Cristian Hesselman (SIDN Labs, University of Twente)

**E-mail** c.e.w.hesselman@utwente.nl

**Teaching team**
- Dr. Pieter-Tjerk de Boer
- Prof. Geert Heijenk
- Prof. Roland van Rijswijk-Deij
- Niels Overkamp (TA)
- Prof. Cristian Hesselman

**Quartile** 1A (Sep 5 thru Nov 11, 2022)

**Academic year** 2022/2023

**Capacity** Max 16 students
Next lecture: **Mon Sep 21, 10:45-12:30**
Programmable networks
SIDN Labs: a more trusted and resilient Internet through use-inspired basic research

Cristian Hesselman

September 7, 2022
SIDN is the operator of the .nl TLD

- Objective: increase society’s confidence in the Internet
- Provide secure and fault-tolerant registry services for .nl
  - Anycasted DNS services with DNSSEC support
  - Registration and domain protection services
- Increase the value of the Internet in the Netherlands and elsewhere
  - Enable safe and novel uses (SIDN Fonds, IRMA)
  - Increase infrastructure security and trustworthiness (SIDN Labs)
- Not-for-profit private organization with a public role based in Arnhem

.nl = the Netherlands
17M inhabitants
6.2M domain names
3.4M DNSSEC-signed
2.5B DNS queries/day
8.6B NTP queries/day
Number of .nl domain names (stats.sidnlabs.nl)
Heterogeneous and fault-tolerant DNS infrastructure

**ns1.dns.nl**
- Sites: NL and abroad
- Operations: SIDN
- Software: various
- Hardware: various

**ns2.dns.nl**
- Sites: worldwide
- Operations: Netnod
- Software: various
- Hardware: various

**ns3.dns.nl**
- Sites: worldwide
- Operations: RCodeZero
- Software: various
- Hardware: various

**ns4.dns.nl**
- Sites: worldwide
- Operations: CIRA
- Software: various
- Hardware: various

**hidprim**
- Sites: NL
- Operations: SIDN

**Signer**
- Sites: NL
- Operations: SIDN

**DRS**
- Sites: NL
- Operations: SIDN

**HSM**
- Sites: NL
- Operations: SIDN

**Registrars**

**Registrants**

**Users**
A more flexible DNS infrastructure (ns1.dns.nl)

- Virtual machines at cloud providers
  - Vultr, Packet (Equinix), Heficed
- Control over VMs and operating systems
- Complements “as a service” and owned infra
- BIRD-based BGP sessions to cloud providers
  - Path pre-pending
  - BGP communities

Anycast2020 sites

BGP tuning based on catchments
ns2.dns.nl (Netnod)
Registration infrastructure (DRS, RDAP, WHOIS, ...)

99.96% availability
Full-automatic failover
Other security areas

• System monitoring and patching (with NCSC-NL and others)

• Secure software development

• Infrastructure penetration testing

• Large-scale and collaborative DDoS mitigation drills (Dutch Anti-DDoS Coalition)

• Security Operations Center (ISO 27001)

• Proactive and collaborative abuse mitigation (phishing, malware, fake shops, etc.)
I Reveal My Attributes (IRMA)

- Solution for decentralized identity management
- Increases users’ data autonomy
- Reduces big tech user profiling
- Enables security verification through open source
- Development at SIDN (from University of Nijmegen)

https://www.sidn.nl/en/theme/online-identity
**SIDN Labs = research team**

- Goal: increase the short and long-term security of our society’s internet infrastructure, for .nl and the Netherlands in particular

- Strategies:
  - Use-inspired basic research (measurements, design, prototyping, evaluation)
  - Make results publicly available and useful for various target groups
  - Apply results at SIDN and elsewhere (“eat your own dogfood”)
  - Work with universities, infrastructure operators, and other labs

- Three research areas: network security (DNS, NTP, BGP), domain name security, new network security paradigms (programmable networks, fundamental design changes)
Example projects

1. Logo detection technology to identify malicious .nl websites [6]

2. Measuring the deployment of newly standardized DNSSEC algorithms [3]

3. Measuring the deployment of newly standardized DNSSEC algorithms [3]

4. Provide well-managed and secure time services [4]

5. Making the IoT more secure and transparent and measure its evolution [5]

6. Experimenting with secure future networks and programmable networks [7][8]

7. Developing a new Internet security and autonomy paradigm [9]
SIDN Labs and Technology Readiness Levels

SIDN Labs focuses on the R in R&D

Operations

Experimental

Fundamental research

https://en.wikipedia.org/wiki/Technology_readiness_level
Examples of our research partners
SIDN Labs team

- Technical experts, diverse in seniority and nationality
- Help SIDN teams, write open-source software, analyze large amounts of data, conduct experiments, write articles, collaborate with universities
- M.Sc students help us advance specific areas
Team culture

• Our added value for the Dutch, European, international Internet community is central

• Flat organization with focus on increasing reliability of the Internet infrastructure

• Cross-fertilization between people for new research and innovation

• Team with professional and self-organizing technical experts

• Leadership provides high-level guidance and facilitates
SIDN Labs history

- End of 2021: 11 colleagues, 10 research engineers
- End of 2018: start of 2STiC
- Beginning of 2017: start of SPIN
- Beginning of 2013: dedicated team (3 colleagues)
- December of 2011: research program
- Summer of 2011: weblog

Volg ons

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 @SIDN
 SIDN

 Q&A

 www.sidnlabs.nl | stats.sidnlabs.nl

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