

CS 5472 - Advanced Topics in Computer Security

Topic 2: Security in Cloud Computing (1)

Spring 2026 Semester

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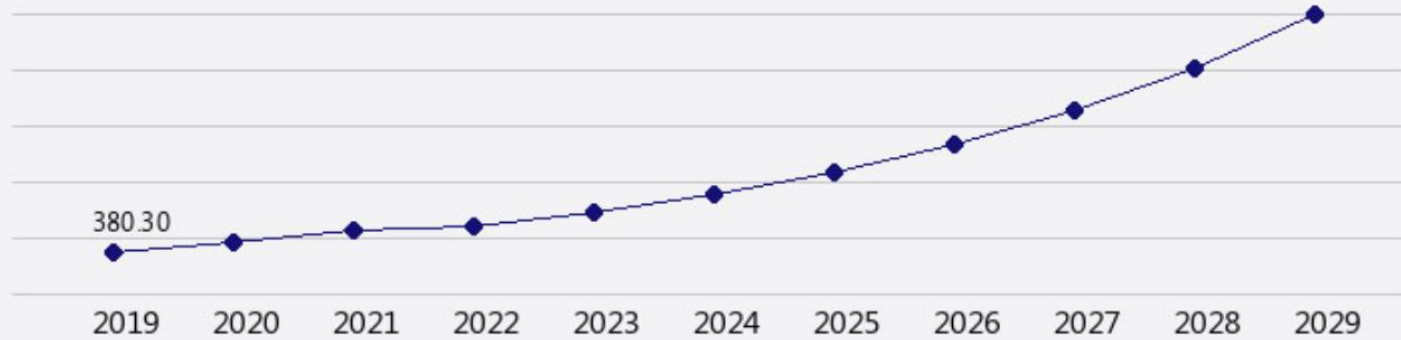
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Clouds are Everywhere Today

Public Cloud Services Market Size 2025-2029 (US\$ Billion)



22.3%
2025 Year-over-Year



ACCELERATING
Growth Momentum



23.1%
CAGR 2024-2029



US\$ 1707.7 Bn
Incremental Growth
between 2024-2029

source: www.technavio.com



Major cloud service providers

Amazon AWS Cloud

The screenshot shows the AWS Management Console Home page in a Windows Internet Explorer browser. The browser's address bar displays the URL <https://console.aws.amazon.com/console/home>. The page features a navigation bar with a 'Services' dropdown menu and a user profile 'tom ryan' with a 'Help' link. The main content area is divided into three columns: 'Welcome', 'Amazon Web Services', and 'Announcements'. The 'Welcome' section provides an overview of the console and links to 'Getting started guides', 'Reference architectures', and 'Free Usage Tier'. The 'Amazon Web Services' section is organized into categories: 'Compute & Networking' (EC2, Elastic MapReduce, Route 53, VPC), 'Storage & Content Delivery' (CloudFront, S3, Storage Gateway), and 'Database' (DynamoDB). The 'Announcements' section includes news items like 'Easily DKIM-Sign Your Emails with Amazon SES' and 'AWS Elastic Beanstalk Now Available in US West (Oregon) and US West (Northern...)'. A 'Service Health' section with an 'Edit' link is also present. The footer contains copyright information and links for 'Feedback', 'Support', 'Privacy Policy', and 'Terms of Use', along with the 'An amazon.com company' logo.

Welcome

The AWS Management Console provides a graphical interface to Amazon Web Services. Learn more about how to use our services to meet your needs, or get started by selecting a service.

[Getting started guides](#)

[Reference architectures](#)

[Free Usage Tier](#)

Set Start Page

Console Home

Amazon Web Services

Compute & Networking

- EC2**
Virtual Servers in the Cloud
- Elastic MapReduce**
Managed Hadoop Framework
- Route 53**
Scalable Domain Name System
- VPC**
Isolated Cloud Resources

Storage & Content Delivery

- CloudFront**
Global Content Delivery Network
- S3**
Scalable Storage in the Cloud
- Storage Gateway**
Integrates on-premises IT environments with Cloud storage

Database

- DynamoDB**
Predictable and Scalable NoSQL

Deployment & Management

- CloudFormation**
Templated AWS Resource Creation
- CloudWatch**
Resource & Application Monitoring
- Elastic Beanstalk**
AWS Application Container
- IAM**
Secure AWS Access Control

App Services

- CloudSearch**
Managed Search Service
- SES**
Email Sending Service
- SNS**
Push Notification Service
- SQS**
Message Queue Service
- SWF**
Workflow Service for Coordinating Application Components

Announcements

- [Easily DKIM-Sign Your Emails with Amazon SES](#)
- [AWS Elastic Beanstalk Now Available in US West \(Oregon\) and US West \(Northern...\)](#)
- [Announcing MFA-protected API access](#)
- [More...](#)

Service Health [Edit](#)

Click [Edit](#) to add at least one service and at least one region to monitor.

[Service Health Dashboard](#)

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What is Cloud Computing?

A model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. This cloud model promotes availability and is composed of five essential characteristics, three service models, and four deployment models.”

--NIST SP-800-145

Cloud Service Models

NIST defines three service models, which can be viewed as nested service alternatives

Software as a service (SaaS)

Google doc

Platform as a service (PaaS)

Heroku

Infrastructure as a service (IaaS)

Amazon EC2, S3, Microsoft Azure

Cloud's Basic Model - Outsourcing



Cloud Storage Outsourcing



- Very popular
 - Dropbox, Google Drive, Microsoft OneDrive, Box, iCloud, Amazon S3, ...
- Very useful and convenient
 - All the data can be stored remotely
 - Access them as you want in any devices
 - No need to maintain a large local storage
 - Good for mobile devices, IoT devices



A Cloud Storage Provider - Amazon AWS Storage



Discover AWS

Products

Solutions

Pricing

Resources

Search

Sign in to console

Create account

Management Tools

Media Services

Migration & Modernization

Multicloud & Hybrid

Networking & Content Delivery

Operations

Security & Identity

Storage



Go to Storage hub

Backup

Centrally manages and automates data protection across AWS services

FSx for Lustre

Fully managed, elastic, high-performance file storage for AI and HPC

FSx for Windows File Server

Fully managed Windows shared file systems with full SMB support

Elastic Block Store (EBS)

High-performance block storage at any scale

FSx for NetApp ONTAP

Fully managed NetApp ONTAP file systems with enterprise features

S3

Object storage with virtually unlimited scale for AI, analytics, and archives

Elastic File System (EFS)

Serverless, fully elastic file storage

FSx for OpenZFS

Fully managed, elastic, scale-out file systems for NAS workloads

[Browse all Storage products](#) →

Traditional Cloud Storage Is Fully Centralized

- The cloud storage provider (CSP) creates, manages, and maintains dedicated IT infrastructures/data centers
 - Users outsource their data to the CSPs' data centers



The most extensive global cloud infrastructure

39
launched Regions each with multiple Availability Zones

123
Availability Zones

750+
CloudFront POPs and 15 Regional edge caches

43
Local Zones & 33 Wavelength Zones for low latency applications

Traditional Cloud Storage Is Fully Centralized (cont.)

- Pros and cons:
 - Pros:
 - easy deployment, easy management
 - Cons:
 - dedicating computing infrastructure, leading to high cost of creating the cloud and hence high price of cloud usage
 - vulnerable to unexpected instances like power outage, flooding
 - do not scale well for the large number of IoT devices

Transitioning Centralized Cloud Storage to Decentralized Cloud Storage

- **Decentralized** cloud storage: connect users who need file storage with hosts worldwide offering **underutilized** hard drive capacity
 - The idea is similar to the **sharing economies** like Airbnb
 - Users from the network form **virtual data centers**



Transitioning Centralized Cloud Storage to Decentralized Cloud Storage (cont.)

- Benefits:
 - **No need to maintain dedicated computing infrastructures**, fully utilize the **spare** disk space from peers. Price is much **cheaper**
 - Sia cloud (\$0.003 per GB per month) vs. Amazon S3 (\$0.023 per GB per month)
 - Much more **robust** by distributing data shares to **multiple peers** across the globally distributed storage network
 - Can be easily **scaled up** to support a huge number of computing devices in the coming IoT era
 - Users outsource data to the **storage peers nearby**, and storing/retrieving data would be much faster

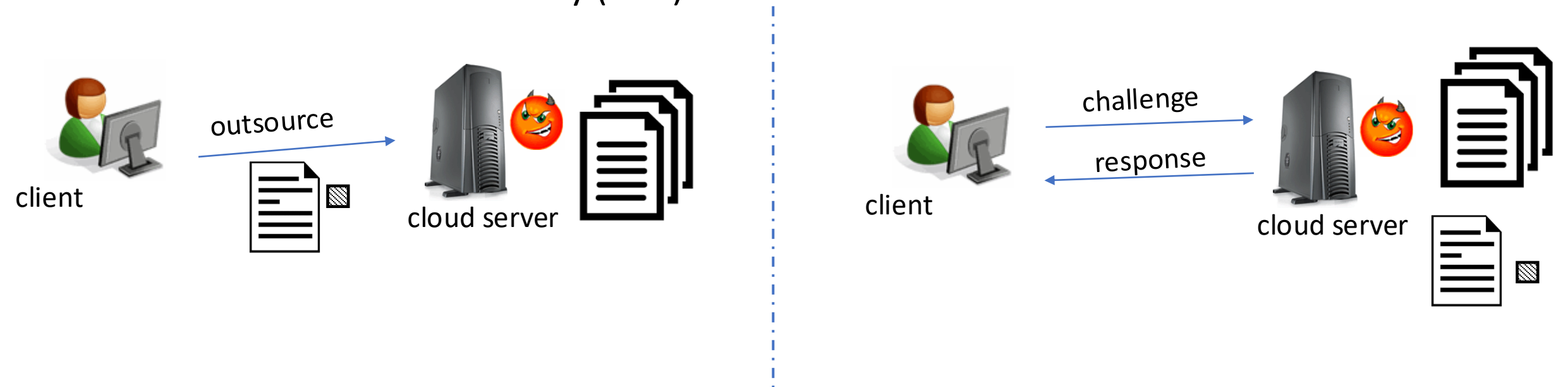
Constructing a Decentralized Cloud Storage Network is Challenging

- How can we **incentivize** the peers to participate
 - Peers (farmers or miners) who will provide storage services
 - Peers (users) who will use storage services
- How to ensure **security** in a purely decentralized storage network in which all peers are untrusted and there is no trusted entity
 - How we ensure the peers will function correctly
 - How to ensure confidentiality of the data stored
 - **How to ensure integrity of the data stored over time**
 - **How to ensure reliability/replication of the data stored**



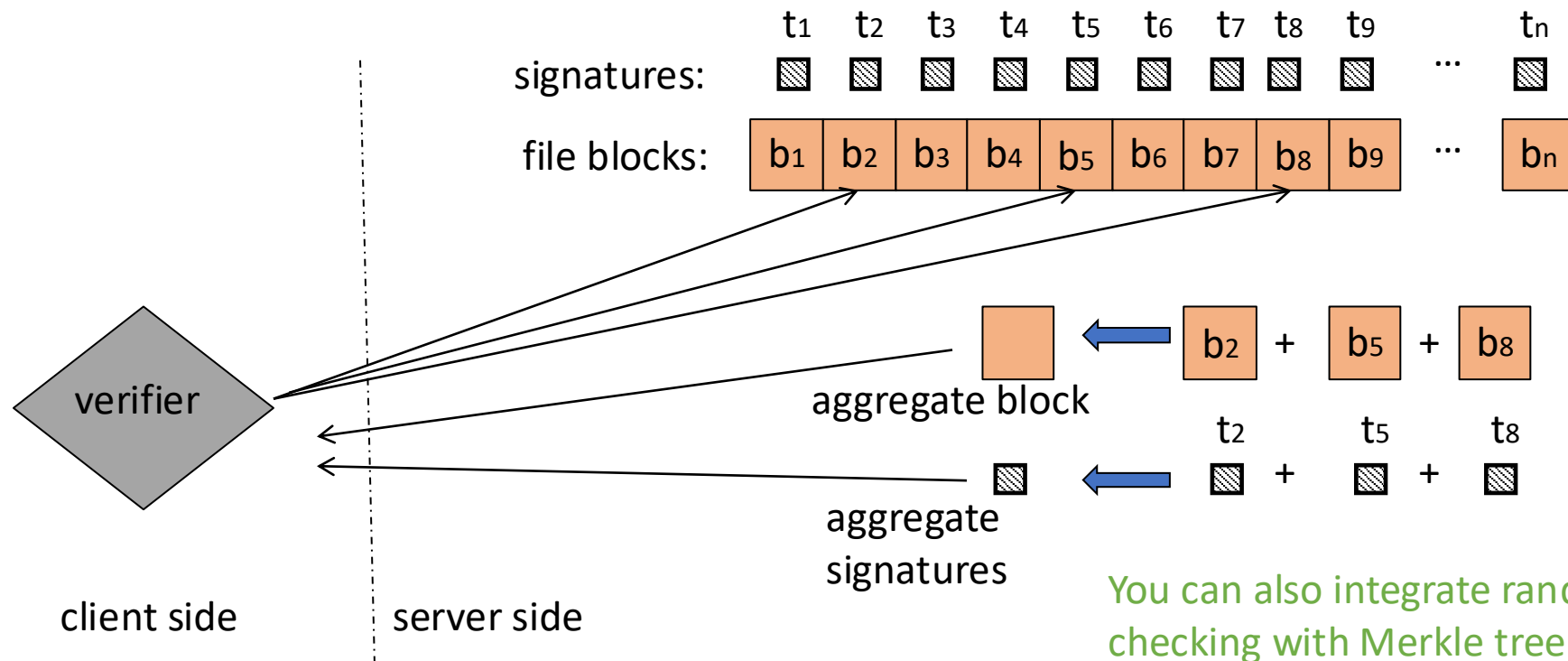
Proofs of Storage (PoS)

- A top security concern in the cloud storage outsourcing is: how can the data owner obtain proofs that the outsourced data in the cloud are stored correctly (i.e., proofs of storage, or **PoS**)
 - Provable data possession (PDP)
 - Proofs of Retrievability (PoR)



Proofs of Storage (cont.)

- A **random checking** technique for efficiency: the client randomly samples a certain number of blocks for checking (**random challenge**)
 - Rather than check the entire outsourced data



You can also integrate random checking with Merkle tree to support efficient data dynamics

Proof of Spacetime and Proof of Replication

- Proof of spacetime
 - PoS can allow to obtain a proof that the data are stored correctly **at the time upon checking**, but cannot ensure that the data can be stored correctly for a **certain amount of time**
 - Proof of spacetime enables this new guarantee
- Proof of replication
 - How can the data owner obtain a guarantee that the outsourced data are indeed stored redundantly in a few different peers
 - The challenge is: even though the cloud storage may claim that 3 copies of the data have been stored, but the storage peers can easily collude and only store 1 copy and it is hard to detect this cheating.

Paper Presentation

- Filecoin: A Decentralized Storage Network
- Presented by Jake Hawley