

Interconnection in the Clouds

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Outline

- **Why “Cloud Interconnection” (and not just Internet Interconnection)**
- **What are research/policy questions**

Dilbert



Internet of Christmas Past

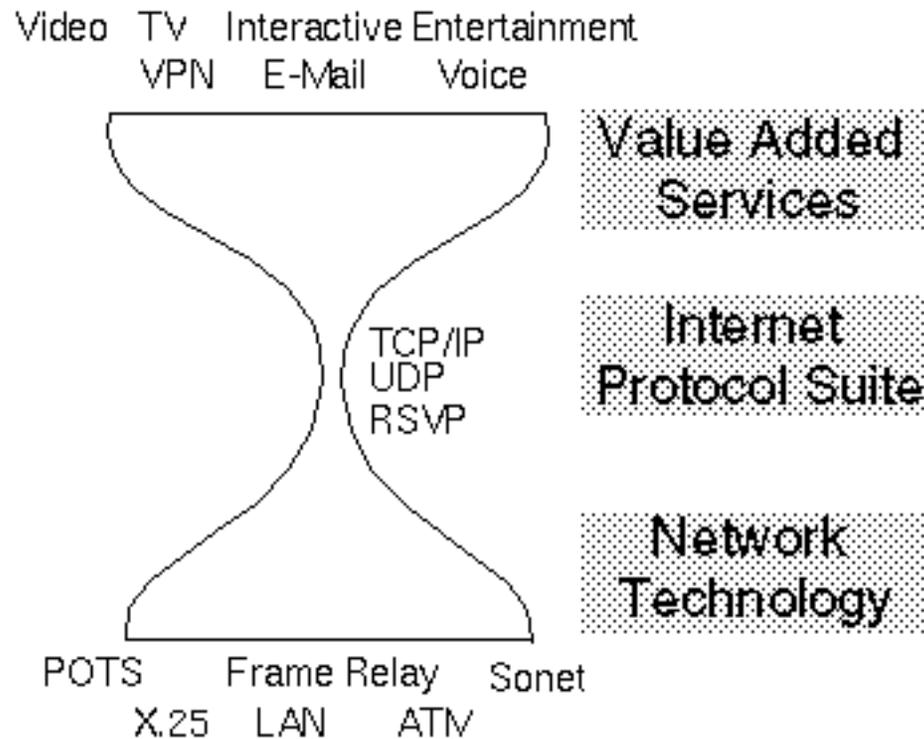


Figure 1: Hourglass-model of the Internet

Source: Stiller et. al., INET98, available at http://www.isoc.org/inet98/proceedings/3e/3e_2.htm

Applications (Verticals)

| | | | | |
|---|---|--|---|---|
| Personal Devices Wearable Computing: pebble, cookoo, re:con, RINGLY, striiv, APX, MOTA, Optimivent, M, wearable intelligence, VUZIX Fitness: GARMIN, senSorics, amiigo, iFIT, LAW BONE, HISPIT, VALENCELL, BASIS, fitbit, tomtom, AROS, LifeBEAM, wahoo Health: LUMO, nanowear, vevsly, kinsol, HAPIfork, soundhawk, SPIRE, Withings, QUANTUS, Lively, CANADU, Thinkle, mcio, blueanatomy, hello, AliveCor, Health, NuMatrix, remee, mclon, corventis, TELCARE Family: FILIP, Sprouting, ovuline, AmberAlert, greatcall, Good Night Lamp, monbaby, OWLET, Secur, BELLABEAR, mimo, Glow, pocketfinder | Lifestyle Sports: sobit, Brain Sentry, BIKESPIKE, Infomotion, biometrics, ZEPP, swingbyte, HAMMERHEAD Cooking: Smart Diet Scale, ANOVA, drop, blossom, iDevices, THE ORANGE CHEF CO., pantry, nomiku Pets: Whistle, PetPace, pintofeed, PetHub, tagg, BISTRO, haytag, FitBark, PetChatz, Petcube, tractive, Petnet, gibi, Petzika Toys: KAROTZ, TOYCLOUD, MAKIES, atoms, UBOOBY, sphero, seebo Music/Art/Video: ROLI, ELECTRIC OBJECTS, gita, CATCH, GOPRO, Narrative Garden: plant link, BITPONICS, radio, EDYN, Greenbox, Koubachi | Connected Home Automation: Quirky, Radiator Labs, netatmo, LEVITON, SmartThings, Ubi, nest, LIFX, gecko, we mo, CRESTRON, smarthome, OLUTRON, Hue, ecobee, AdvancedLumens, vivint, SAVANT, vera, INSTEON, CHAMBERLAIN, PROPER, LIGHTIFY, somfy Monitoring: lapka, sense, birdi, BlueMaestro, SUPERMECHANICAL, leeo, knot, CUBESENSORS, tado°, ambient Security: HomeMonitor, canary, ring, OK+DOKEYS, dropcam, butterflye, Lockitron, piperc, globosense, genie, UNIKEY, Kwikset, GOJI, scout, SmartAlarm, KeyMe, SimpliSafe Tracker: Chipolo, linquet, LoCCA!, TrackR Hub: Homey, revolv, NINJABLOCKS, Control, LOWE'S, zonoff, STAPLES, NEXIA, muzzley, wink | Industries Retail: leapt, PROXIMITY, SWIRL, bytelight, euclid, mahaana, GIMBAL, PERCH, boni, PassKit, VERIFONE, LevelUp, belly, payleven, con Payment: Square, shopify, PayPal, ACS Healthcare: ViSi, Senseonics, STANLEY, Abkcebnx, VITALITY, MedMinder, TeleTracking, MedSignals, AdhereTech, VERSUS, CENTRAK, intelligent, Sotera, iKlydian Automotive: Zbbe, nifty, INRIX, navdyDELPHI, dash, waze, OpenXC Infrastructure: wavelink, iBeam, kisi, Johnson Controls, Trimble, Robin, Schneider Electric, SMART STRUCTURES, WiTricity, SIGAF MACHINE Agriculture: adapt-N, Ag Leader | Industrial Internet Robotics: Double Robotics, ALDEBARAN, HARVEST, XENEX, ROBOTIX, EMPIRE, KIVA Systems, LUBOLS, CLEARPATH, EX, ABB, LIQUID ROBOTICS, Jibo Drones/Aerospace: SDR, KMEI, Airware, SKYCATCH, spire, DJI, Parrot, Skybotix, Skyward, wellstar Green-tech: BigBelly, enlightened, Smart TRASH, Genevo, compology, AMPY 3D Scary/Print: MakerBot, Stratasys, HOREL 3D, formlabs, M3D, matterport, FUEL3D, AIO, NEXTENGINE, RepRap, Matterhorn, FAB, Ultimaker, occipital, DAVID, FSLD, Solidoodle Smart Grid: GRID NET, e-on, Silver Spring, SMART GRID CLUSTER, Itron, Trilliant Asset Tracking: asap, vilo, MESH SYSTEMS, COBRA, ekahau, RASANT, Flectmatics, BIV, Impinj, CUBIC, asustor, Apricity |
|---|---|--|---|---|

Platforms & Enablement (Horizontal)

| | | | | | | |
|--|--|---|--|---|--|---|
| Connectivity/Dev Platforms spark, kynetx, pinoccio, ioBridge, Ayla Networks, EUROTECH, resin.io, Symplic, TESSEL, bluecity | Software/Data Platforms EXOSITE, iconcontrol, thingsquare, carriers, Keen IO, SeeControl, Lings, ConnectHQ, NewAer, BERG, Axeda, Yaler.net, RacoWireless, SpaceCurve, FITT, greenWAVE, ARRAYENT, swot.io, ZALAR, Cyberlighting, altiux, Yo, ThingWorx, DN2K, people power, IOTC, thingful, CANDI, bugs, worm, TempIQ, evercam.io, covisint, aler, Jasper, GroveStreams, ETHERIOS, PubNub, INFLURA, SensorCloud, xively | Open Source webinos, AllJoyn, openHAB, nimbis.com, OPEN INTERCONNECT, ThingSpeak, GRID2HOME | Sensor Networks SAFECAST, placemeter, Motionloft | Personal Interfaces NeuroSky, Rapsion, lin, Interaxon, wit.ai, LEAP MOTION, gestigon, speech, THALMICLABS, LINTUIGNE, api.ai, EMO TIV, Maluuba, Reemo, Oculus | Security inside, SafeNet, utimaco, escrypt, gemalto, BASTILLE NETWORKS, MOCANA | Corporates amazon, hp, LG, intel, htc, PHILIPS, IBM, SAMSUNG, Google, WIND RIVER, MOTOROLA, belkin, DELL, BOSCH, NATIONAL INSTRUMENTS, ARM, LogMeIn, Microsoft, Honeywell, TEXAS INSTRUMENTS, SONY, Atmel, SIEMENS, QUALCOMM, CISCO, TOSHIBA, BROADCOM, SHARP |
|--|--|---|--|---|--|---|

Building Blocks

| | | | | | | | |
|---|---|--|--|--|---|--|--|
| Protocols Bluetooth, XMPP, Weaved, MQT, RFID, NFC, RuBee, Wi Fi, ZigBee, oMA, WAVE, enModus, HART, miWi, M-Bus, 2G, 3G, 4G, LTE, CoAP, 6LoWPAN, LWM2M, BITXmI | M2M Networks Helium, SIGFOX, KORE, stream, aeris, MACHEN, M2M | Portable WIFI Open Garden, GOODSPEED, BRCK, karma | Telecom at&t, boostmobile, Verizon, T-Mobile, China Mobile, Telefonica, VimpelCom, Sprint, US Cellular, Vodafone, airtel | M2M pslick, FBCCOM, Laird, WICED, QMSmart, Wireless, seed, arkessa, enOcean, ecnais, GainSpan, Wozym, Telit, SIERRA WIRELESS | | | |
| Cloud Google Cloud Platform, amazon web services, ORACLE CLOUD, Microsoft Azure | Mobile iOS, Android, Windows Phone, BlackBerry | Processors/Sensors ARDUINO, XILINX, beagleboard.org, ESPRIMO, VARIABLE, Ubeum, SLNS, PLK, Cortex | Parts/Kits Makey Makey, SAM, reedymate, littleBits, TinkerForge, WUNDERB | Services TIN, dragon, makexyz, sculpteo, radfruit, CIRCUIT LAB | Incubators Highway 1, LEMNOS Labs, WEARABLE WORLD, R/GA Accelerator, TechShop | Funding KICKSTARTER, indiegogo, MedStart | Distribution GRAND ST., angelcam |

Cloud Interconnection – Policy Challenges

Internet becoming “cloud”

- “packet transport” → transport + in-network storage/computing
 - (maybe also trust, payment model, or other value components)
- “Internet” is essential socio-economic infrastructure.

Interconnection Policy Concerns

- Universal service ⇔ Availability, Affordability, Quality
- Interoperability ⇔ Reach, Competition, Complements/Substitutes
- Evolvability ⇔ Innovation, (Entry barriers)

What is “Internet”?

What is narrow waist(s) of Clouded Internet?

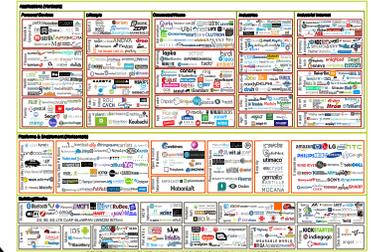
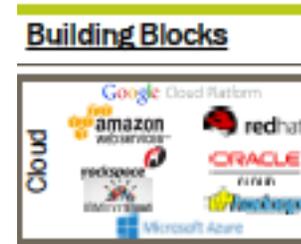
Cloud Interconnection – today's research question



SaaS

PaaS

IaaS



Q: How are IaaS/PaaS cloud platforms interconnected?

- E.g., Amazon Web Services, Google Compute Engine, Joyent, etc..
- (already asking this for CDN-ISPs ...)

Q: Is performance different for different platforms?

- What metrics/data needed? (How is measurement challenge different?)

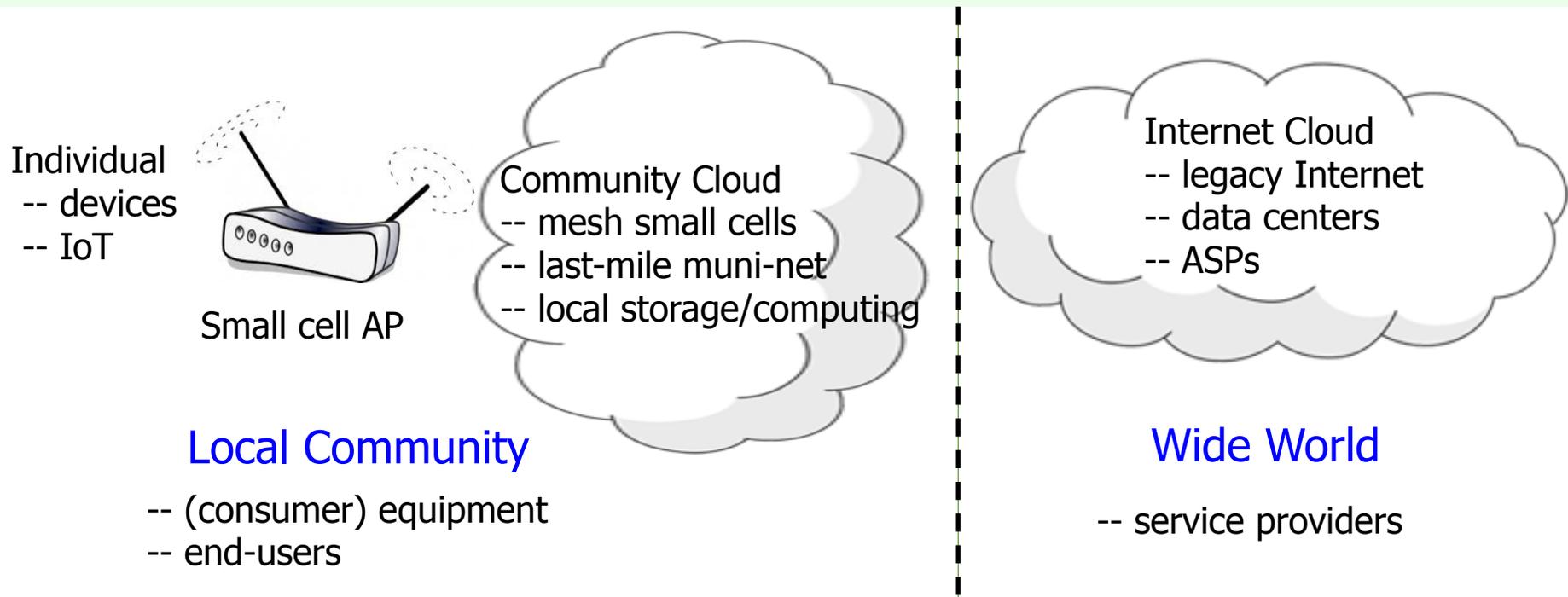
Q: How easy is it to switch platforms?

- (How easy was it for Netflix to switch its CDN strategy?)

Q: How does cloud architecture impact total costs/performance?

- (Benefits of CDN/ISP joint cache positioning?)

Community Clouds – a step further



Q: End-user/Community deployed networks as access alternative?

- Wireless makes feasible new vector of competition.
- Wireless enables new models of connectivity (e.g., IoT)

Q: Cloud functionality in local network?

- Local storage/computing or rely on Internet cloud resources?
- Edge control of cloud resources?

Q: Policy challenges? Muni-networks, spectrum, local zoning....

If Internet Cloud is future....

Q: How did tech, market, and *policy* impact cloud design?

| Intermodal Transit | Railroads & Public Transport | Highways & private vehicles |
|--------------------|-----------------------------------|---|
| Power grid | Renewables and bidirectional grid | Large generation & long-haul transmission |

Q: Is U.S. Post Office a vision of future of Internet?

Q: FIA and Clouds: can we design the future we want?

- Mobility: all resources subject to granular allocation (time, space, context)
- Dynamic: on-demand, real-time responsive (elastic supply)
- End-user controllable (responsive to local context)
- Evolvable
- Secure



Additional Slides – back-up/not used.

Future vision: from Internet to Clouds

Pervasive computing:

- everywhere/always/everything connected, aware and unaware
- IoT (M2M), Big Data, Clouds \Leftrightarrow Real/Virtual world integration

Internet to Clouds

- Packet transport => transport, storage, computing *and more....*
- Future Internet Architectures
 - Flexible, customizable, end-user controlled
 - From end-to-end to *trusted-to-trusted*
 - Mobile in all dimensions (time, space, context). Users/resources.

Infrastructure implications:

- Smarts everywhere (edges, networks). Distributed intelligence.
- Wireless everywhere, all kinds/all uses (not just communication)
- Fat *and* Thin clients
- Small cells: resources are local, dynamically controllable (owned?)

Clouds: next big thing for network providers?

Value proposition : transport + distributed computing + storage

Just-in-time/anywhere on-demand resources

Resource pooling

Thin/thick clients, mobile/fixed, wired/wireless

Reliability: redundancy, diverse routing, security (?)

Energy efficiency & cost saving : scale economies, maintenance

Clouds: who owns assets? Customer relationship? Application?

XaaS (X=I, P, S, ?): General purpose/specialized? Public/private?

Smart edges (Dumb pipes) v. Smart networks

Challenges: divide the pie!

Control ⇔ Interoperability

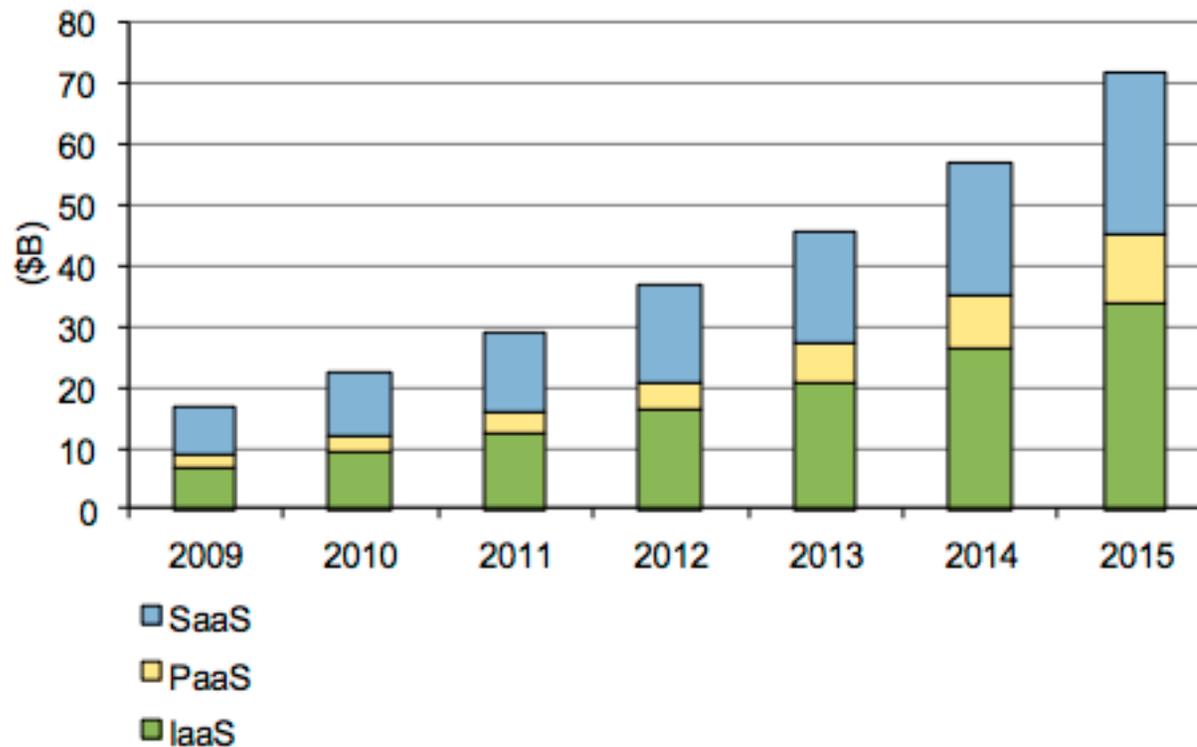
Shared resources ⇔ Cost recovery

Regulatory uncertainty: (telephony) PSTN → cloud computing utility

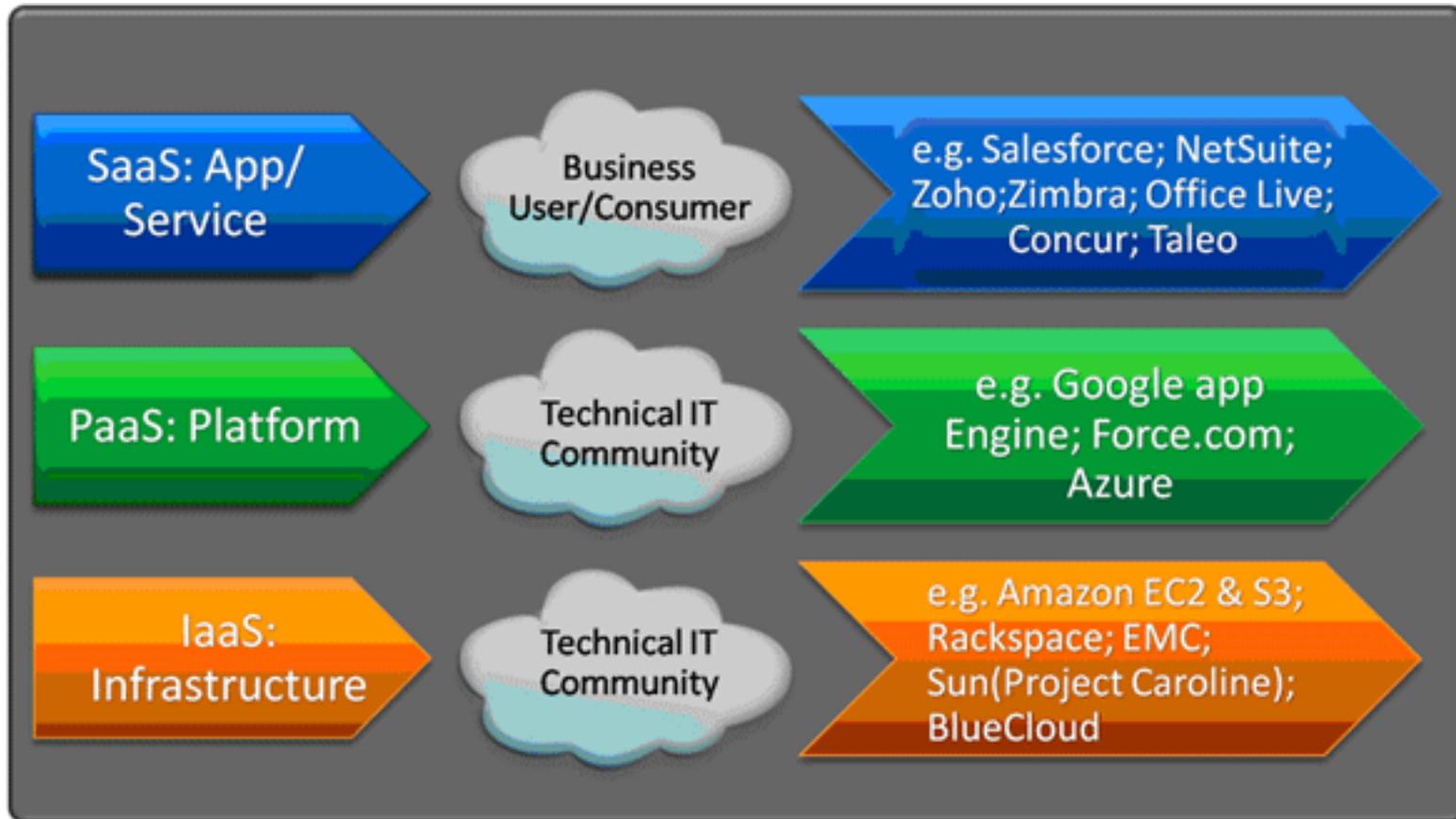
Cloud Services : \$28B (2011) → \$70.8B (2015)

SaaS (\$13B), PaaS (\$3B), IaaS (\$12B)... 26% CAGR

Worldwide Public IT Cloud Services Segmented by Primary Market, 2009–2015



Source: IDC, 2012



The Internet of Things

