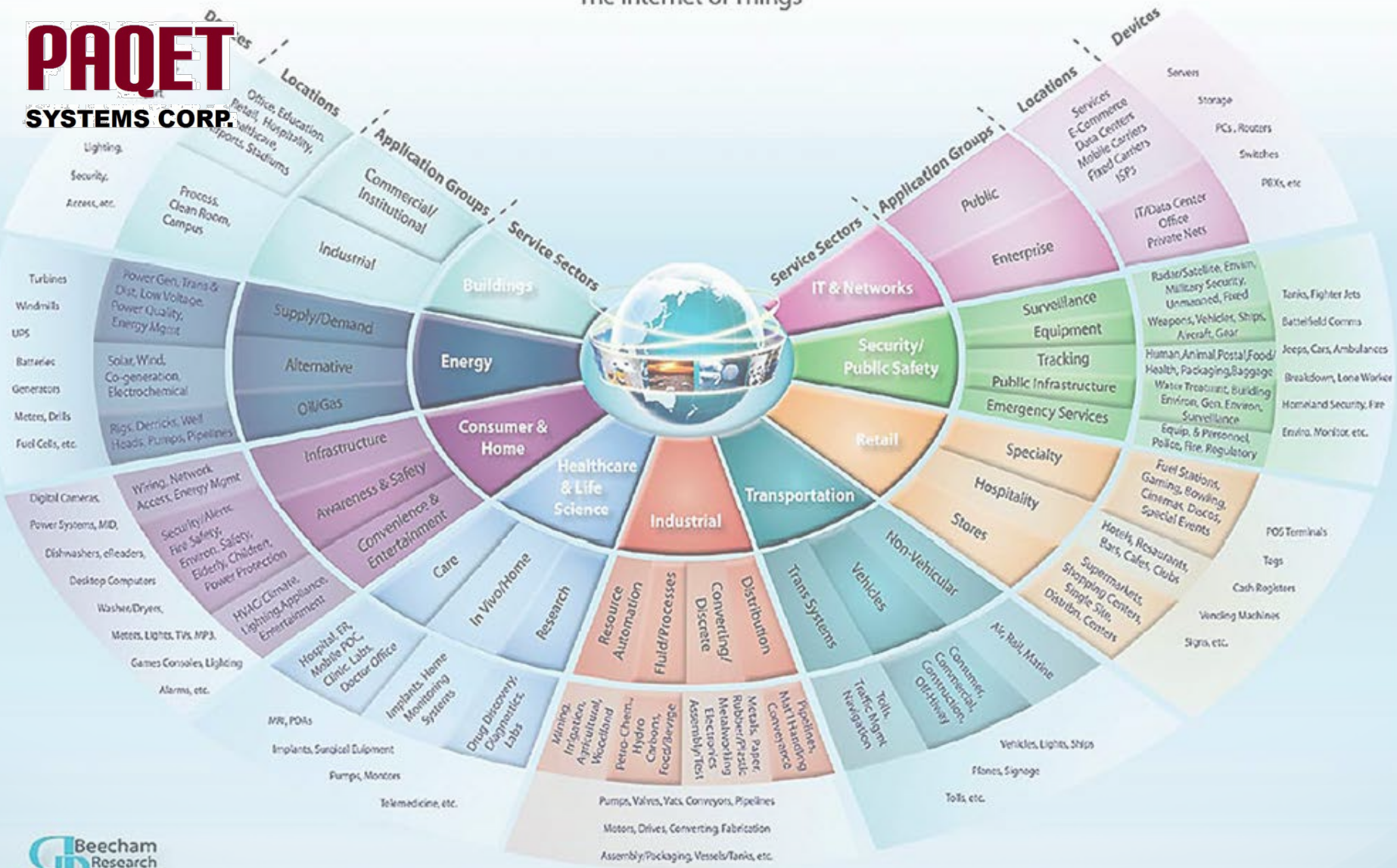
PAQET SYSTEMS CORP.

The Internet of Things



Beecham Research

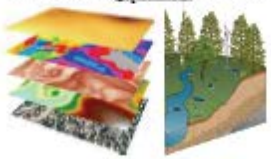
50 Billion devices connected to the Internet, $19 Trillion market, 1 Trillion sensors by 2020 – Cisco

New Operating System for the Internet of Things

What is the Internet of Things? (IoT)
Why now? What are the enablers?
IoT Node design challenges
New IoT Operating System approach
Benefits of Paqet OS in IoT applications

The Internet of Things: A Broad Set of Applications

Predictive maintenance



Enable New Knowledge

Energy Saving (I2E)

Intelligent Buildings

Defense

Industrial Automation

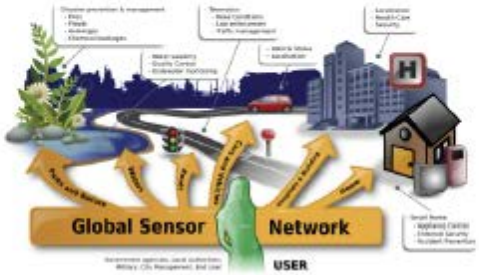
Transportation and Connected Vehicles

Enhance Safety & Sec

Agriculture

Healthcare

Smart Grid

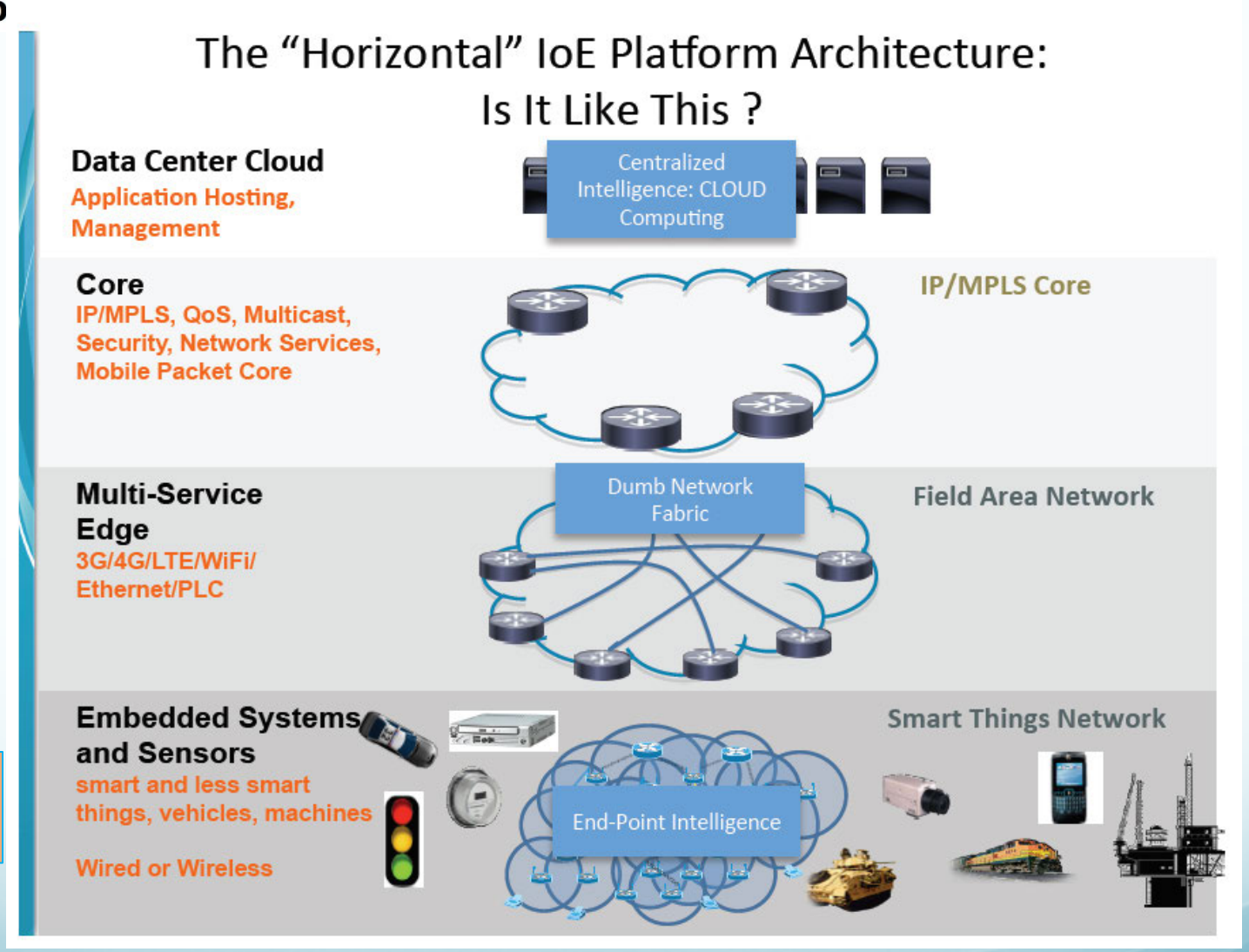


Smart City

Smart Home

Source: Cisco, Flavio Bonomi

Cisco: Internet of Everything



IoT Node

Source: Cisco, Flavio Bonomi

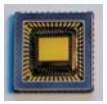
IoT Node

Must haves:

SOFTWARE
Operating System

Temp, Pres, Hum

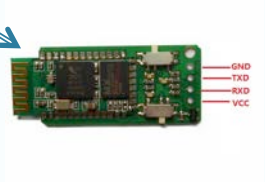
Acc, Gyr, Mag



SiP

Sensors

MCU -RAM/Flash

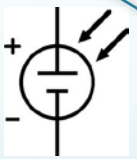


RF Communications

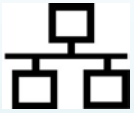
May have:

External power

Battery



Energy Harvesting

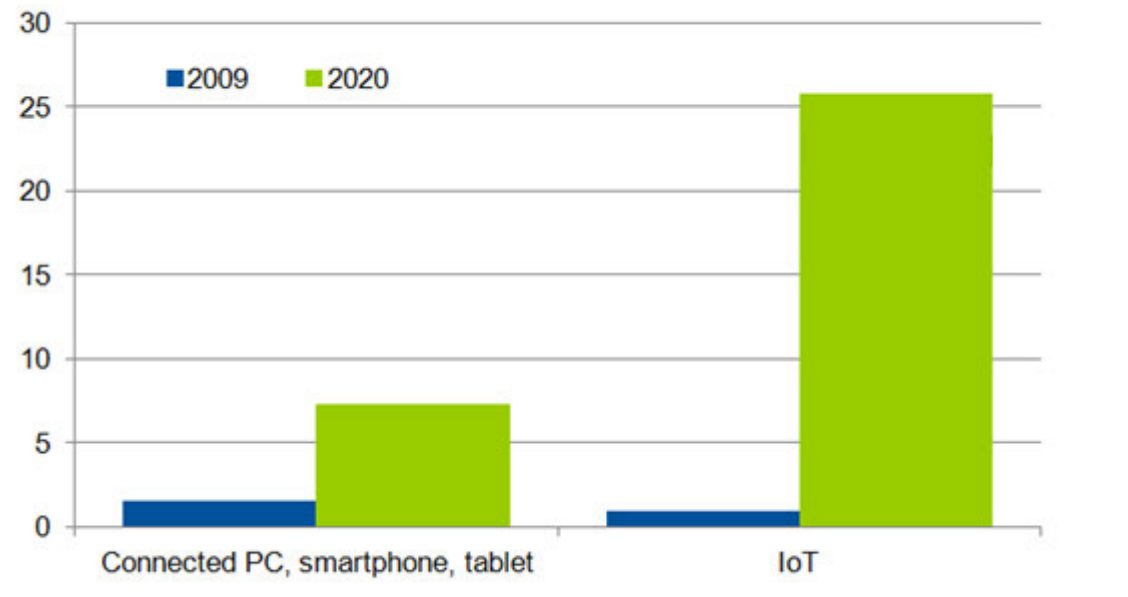


Wired IP or Serial

SOFTWARE
Applications

IoT Projections

Figure1. Total of Connected Devices, Billions of Units (Installed Base)



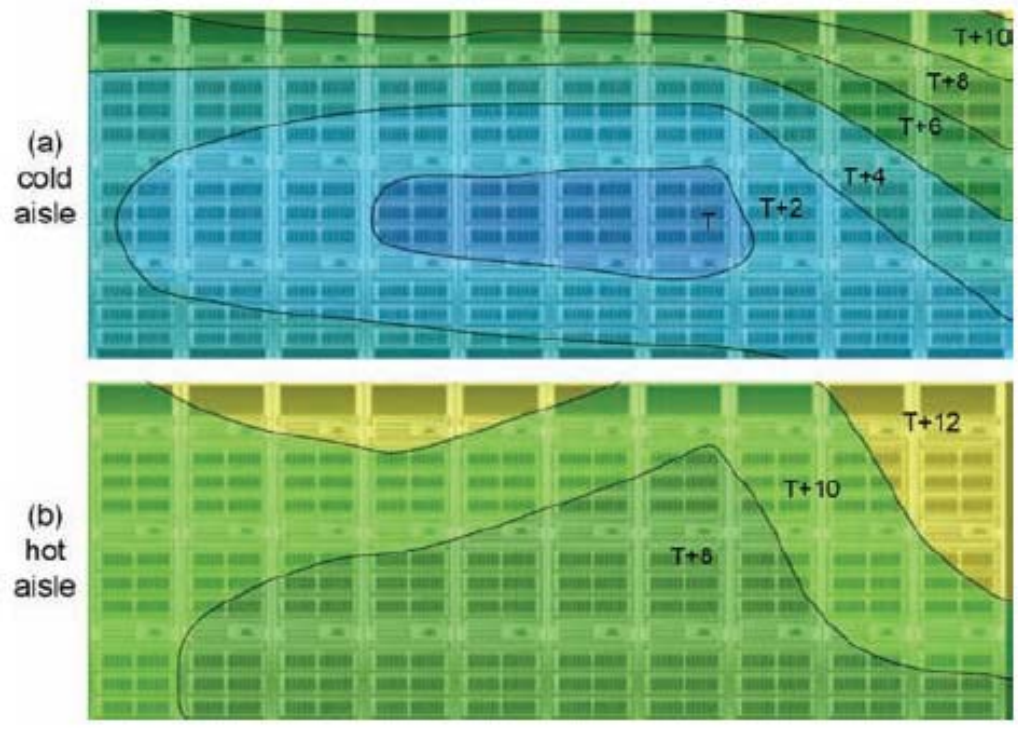
Source: Gartner (November 2013)

PAQET SYSTEMS CORP.

Big Companies Already Get It

CISCO
NIKE
Texas Instruments
at&t
BOSCH
Honeywell
fitbit
QUALCOMM
ECHELON
hp
Yale
GE
SAMSUNG
ST
NXP
nest
JAWBONE
Kwikset
A BLACK&DECKER COMPANY
xively by LogMeIn
InvenSense
Google
freescale semiconductor
intel
pebble
nuvoTon

Value of autonomous sensors



Heat map of a data center

Benefit from Sensors:

- Monitor temperature, humidity, air flow, air quality, current
- Allows reduction or elimination of air conditioning
- Mega data center can deploy 4,000 to 20,000 sensors

Benefit from Wireless:

- **Wireless sensors cost 1/10th that of wired sensors due to labor & wiring costs**

Source: Microsoft, MegaWatt Consulting

New IoT operating system

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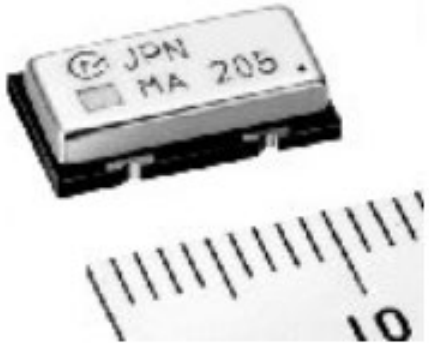
Motion Sensor: A Disruptive Solution

From 2003 to 2013	Improved
• Size	>100x
• Cost	>10x
• Performance	>10x
• Power	>20x
• Production Volume	>100x
• Turn key solution	



~12x5x2mm
Single Axis

3x3x0.9mm
6-axis

Nasiri Ventures

Source: Steve Nasiri

MEMS manufacturers shipping billions

Billions of MEMS Devices Sold

Avago	>2B	Cell phone filters	As of Q2 2010
Robert Bosch	>1B	Automotive sensors	As of Nov 2008
Knowles	>1B	Microphones	As of Sept 2009
Texas Instruments	$>10^{14}$	Light modulators	As of Dec 2009
GE NovaSensor	>750M	Pressure sensors	As of Aug 2011
ST Micro	>1B	Accels and Gyros	As of Dec 2010
HP	"Billions and Billions of ink jet nozzles"		
Cepheid	~$1B	Microfluidic systems	As of Q4 2010
SiTime	>100M	MEMS Oscillators	As of Q2 2012

MEMS Engineer Forum 2013

Source: Kurt Petersen, MEMS Engineer Forum 2013

Potential Sensor Platforms

- **Motion Tracking Platform:**
  - Gyro, Accel, Compass, Altimeter, Microphone, Bolometer...
- **Clock and Filters Platform:**
  - Clocks, Resonators, Filters, Tuners,…
- **Ambient Sensor Platform:**
  - Oxygen, Chemical, Light, Proximity,…
- **Health Monitoring Platform:**
  - Heart, Temperature, Sugar,…
- **Physical Platform:**
  - Auto Focus, Stabilization, Touch, Joystick,...

Nasiri Ventures

Source: Steve Nasiri

Three **ENORMOUS IoE** Initiatives

Source: Kurt Petersen IEEE talk, TSensor Roadmap, HP

ARM dominates IoT

ARM in the Internet of Things

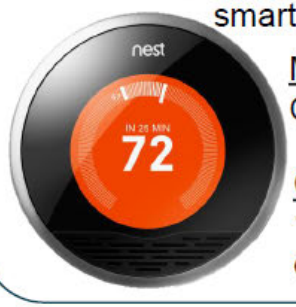
>3 billion

ARM-based embedded computing chips shipped in 2013

160

Companies enabled with Cortex-M processor technology

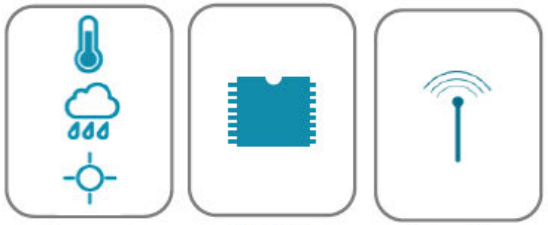
Multiple Opportunities per smart device



Main processor
Cortex-A or Cortex-M

Connectivity
1-2 Cortex-M based chips

ARM-based microcontrollers are being combined with radios, sensors and controllers to create new markets



Sensor	MCU	Radio
ARM Share:	**22%**	**>75%**

Wearables showing momentum with 10's millions shipping in 2013

>70 ARM-based wearable designs in flight

>200m unit market in 2018*

* Source: IMS Research, Juniper Research

Source: ARM 2014

Plunging IoT costs

	2012	2016	2020
ARM Cortex M0+	$ 0.49	$ 0.30	$ 0.30
Software	$ 0.20	$ 0.15	$ 0.10
Bluetooth LE	$ 0.75	$ 0.35	$ -
MEMS Sensor	$ 1.30	$ 0.65	$ 0.40
Battery	$ 0.40	$ 0.30	$ 0.20
PV	$ 0.30	$ 0.20	$ 0.20
Electronics & Packaging	$ 1.00	$ 0.70	$ 0.50
COGS in volume	$ 4.44	$ 2.65	$ 1.70

Estimated IoT node costs could drop dramatically

Source: ARM, Gartner, Paqet, Nasiri

Summary: IoT Enablers / Pain Points

Sub system	Current state of art	Future
MEMS sensors: Low Cost & Power	MEMS motion sensors sub $1 2011	Atmospheric & optical sensors in MEMS
Microcontrollers: Low cost & power 32 bit	ARM Cortex M series 3rd generation - 2012 >6 big suppliers	Sub threshold MCU 4th gen ARM 32 bits/32 cents
Radios: low power, mesh	Multiple low power PAN radios & standards	Integrated radio Low power mesh
Power source	Alkaline, Lithium Li-Ion	Harvesting: PV, Vibe, Temp
Operating System	Embedded RTOS from 80s & 90s + Hand Chiseling	Purpose built IoT: Ultra low power Ultra small footprint
Application/ analytics	Hardware specific code, eg MCU, RF, Sensor dependencies	Virtualizable hardware using IoT O/S

New IoT operating system

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IoT Hardware Characteristics

Embedded microcontroller has limited resources: ARM M series

- Memory Flash ROM ranges from 2 kB to 256 kB
- RAM ranges from 2 kB to 32 kB
- Typically serial I/O: SPI, I2C, UART

But I wanted that $0.50 ARM! Typically M0+

- Memory Flash ROM ranges from 2 kB to 16 kB
- RAM ranges from 2 kB to 4 kB

Dozens of radios:

- High Power: WiFi
- Low power standards: ZigBee, Z-wave, ANT+, Bluetooth Smart
- Low power proprietary: sub GHz, Dust, GreenNet

Thousands of Sensors – different interface/registers/calibration:

- Motion/force: Accelerometer, Magnetometer, Gyro, Strain
- Atmospheric: Temp, humidity
- Light: Gas sensors, spectrometers

IoT ARMs: Cheaper and less filling

	CPU	Flash	SRAM	Active/ deep shutdown	MSRP @10ku
NXP	Cortex M0$^+$	4kB	1kB		$0.49
	Cortex M0$^+$	8kB	2kB		$0.58
	Cortex M0$^+$	16kB	4kB	2.8 ma/ 0.22 µa	$0.68
NXP	Cortex M3	8kB	2kB		$1.00
	Cortex M3	16kB	4kB	14 ma/ 0.63 µa	$1.72
	Cortex M3	32kB	4kB		$1.60

=>Within M0$^+$ reducing memory saves $0.20 in system cost
=>Drop from M3 to M0$^+$ saves $0.50 to ~$1.00 and 80% active power!

Embedded Operating systems

A. Real Time (RTOS) for embedded

20 years embedded development/ most are open source
Focus on fast interrupt response, deterministic response time
Typical OS desires > 64 kB flash (plus application)
Conventional embedded applications running on beefy power:
Automotive, industrial control, appliances

Features:
Fast Interrupt processing
Deterministic behavior
Multitasking, multithread
Protected, user modes
Open Source

Challenges:
Too Big > 64kB
Poor OOBE
Not extreme power optimized
Everyone has the source
? Security

Source: OS research, interviews, Thingsquare seminar

Thingsquare/Contiki memory

thingsquare

Typical IoT hardware properties

- Microcontroller
  - Memory
    - Flash ROM on the order of 64-512 kilobytes
    - RAM on the order of 8-32 kilobytes
  - I/O to connect sensors and actuators
    - Serial ports, ADCs, SPI, etc
- Radio
  - External transceivers
  - Systems-on-a-Chip
    - Radio integrated with microcontroller

slideshare 8 /51

thingsquare

Radio hardware

- Microcontroller + transceiver
  - CC1120 – sub-GHz
  - CC2520 – IEEE 802.15.4
  - nRF8001 – Bluetooth Smart
  - CC3300 – WiFi
- Connected via SPI
- System-on-a-Chip
  - CC2538 – IEEE 802.15.4 + ARM Cortex M3
  - Broadcom Wiced – WiFi + ARM Cortex M3

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FreeRTOS memory

Claim
23K

FreeRTOS™

Internet of Things

"We provide the infrastructure that enables your innovation"

Real Time Engineers Ltd have partnered with Nabto to develop FreeRTOS+Nabto, a product that brings simplicity, platform independence, and entry level access to Nabto's peer to peer Internet of Things solution.

Click to enlarge image

FreeRTOS+Nabto is a small piece of C code (23K inclusive of FreeRTOS and the IP stack) that, when integrated into an embedded networked device, allows that device to be remotely accessed and controlled using a rich web based user interface or intelligent data acquisition system.

See how we solve the challenges posed by the Internet of Things . . .

Actual out of the box: 42K+ 29K

```
Done executing task "RunCompilerTask".
Using "RunOutputFileVerifyTask" task from assembly "C:\Program Files
Task "RunOutputFileVerifyTask"
            Program Memory Usage     :    41728 bytes    15.9 % Full
            Data Memory Usage        :    28368 bytes    86.6 % Full
Done executing task "RunOutputFileVerifyTask".
```

High cost of free operating systems

- **Old architectures**
  - Poor power management
  - Too big out of the “box”: 44k to 96k
  - Need High end of ARM M series
- **High Total Cost of Ownership**
  - Build an OS porting team to:
    - Strip out unused features to reduce size
    - Customize for ARM MCU features
    - Add IPv6 & power management
  - Complexity increases as IoT deployments grow
- **Not secure**
  - Source code widely available => think Open SSL
  - Nodes may not be updateable for security flaws

New IoT Operating System

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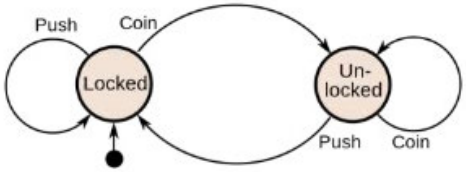
A new approach

B. State Machine => How Internet works

Most internet stacks are state machines, Event Driven
Good for simple functions, small data streams, small code size
Harder for programmers to build a state machine in an RTOS
Solution: Build State Machine into the OS ground up

Programming concept: Event driven / state machine

- Reactive - events control program flow
  - Timers, hardware interrupts, radio, etc
- More kind on resources
- However, callbacks and state variables makes programming harder



State used in low power radios

IEEE Consumer Electronics Society

Short range wireless applications areas

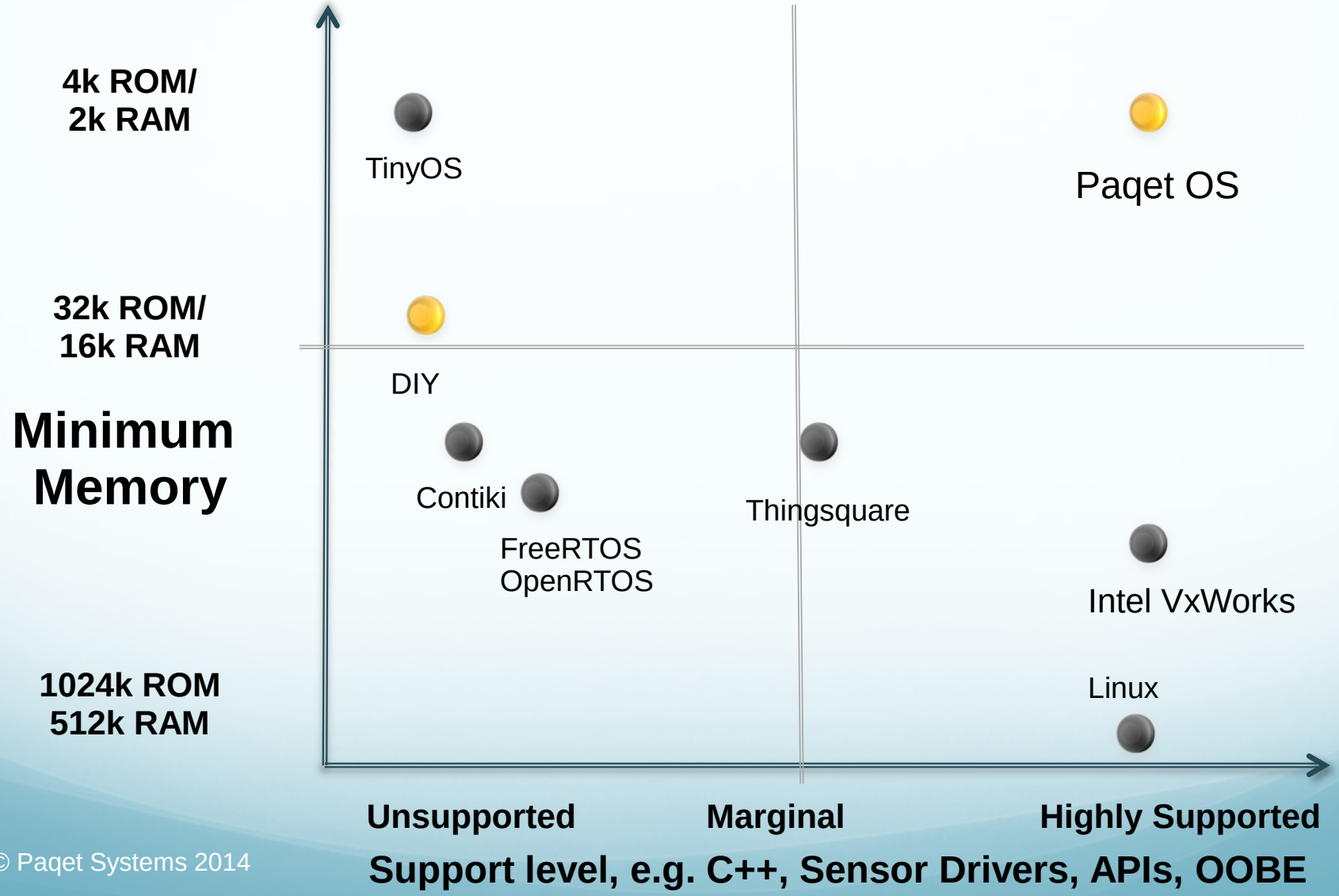
	Voice	Data	Audio	Video	State
Bluetooth ACL / HS	x	Y	Y	x	x
Bluetooth SCO/eSCO	Y	x	x	x	x
Bluetooth low energy	x	x	x	x	Y
Wi-Fi	(VoIP)	Y	Y	Y	x
Wi-Fi Direct	Y	Y	Y	x	x
ZigBee	x	x	x	x	Y
ANT	x	x	x	x	Y

State = low bandwidth, low latency data

Low Power

Source: Joe Decuir, CSR, Presentation to IEEE CES

IoT OS: Memory vs. Support



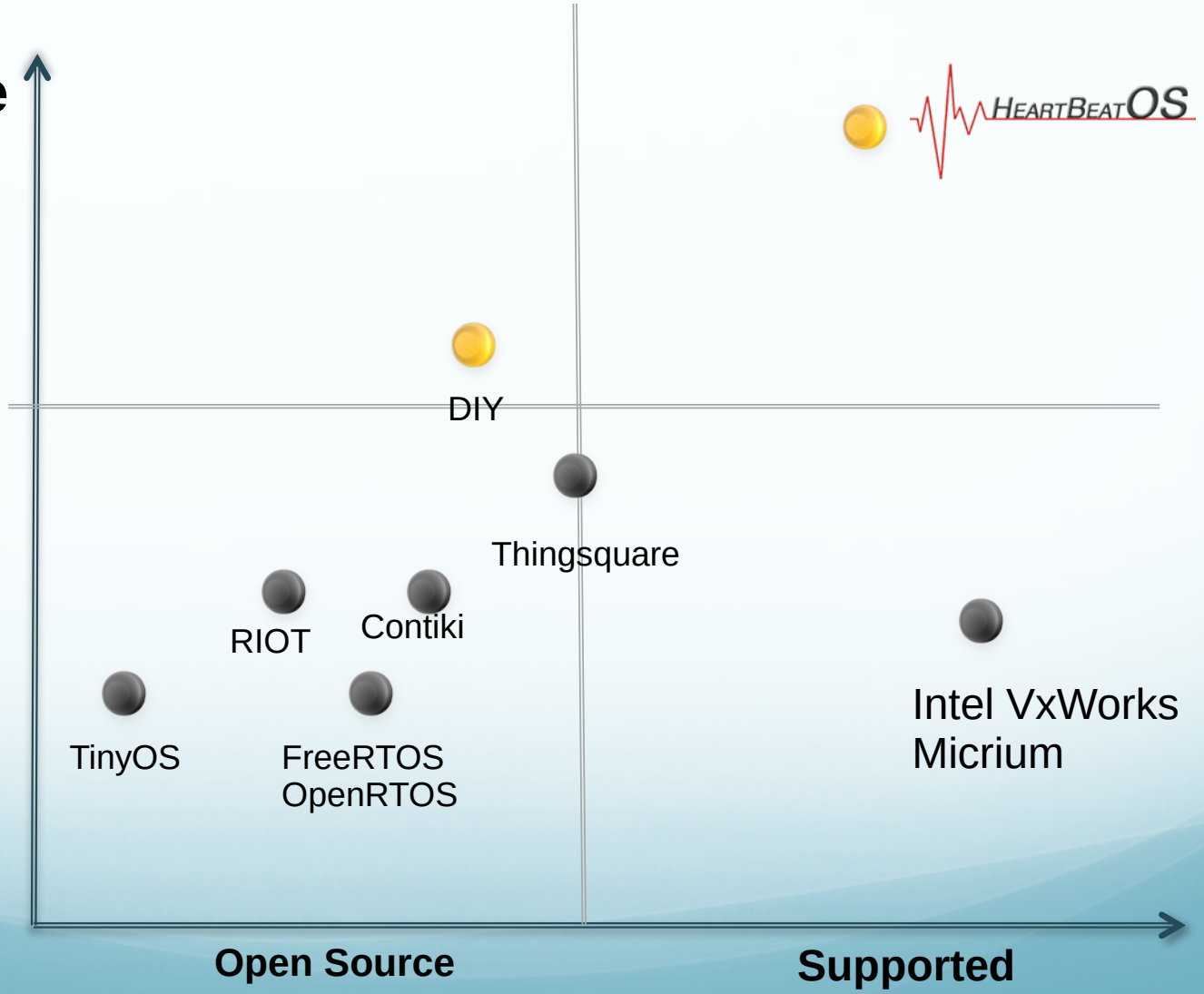
IoT OS by Type

OS Structure:

State Machine

Event Driven
Ultra Low Power

Real Time



New IoT operating system

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Drivers of power in IoT nodes

Duty Cycle: how often active

Radio: Standards, protocol efficiency

CPU: *OS # cycles, Fast CPU wakeup, "Reflex" support*

Active power consumption:

Radio: Tx Power, Rx Power, PA efficiency, simple protocols

CPU: *State OS, Simple CPU, XIP,* slow clock, latest S/C node

Duration of active state:

Radio: High data rate, least energy/bit, simple protocol

CPU: *State OS, Simple OS, native IPv6 support,* number of cycles to complete

Standby power consumption:

Radio: Leakage better for older S/C node

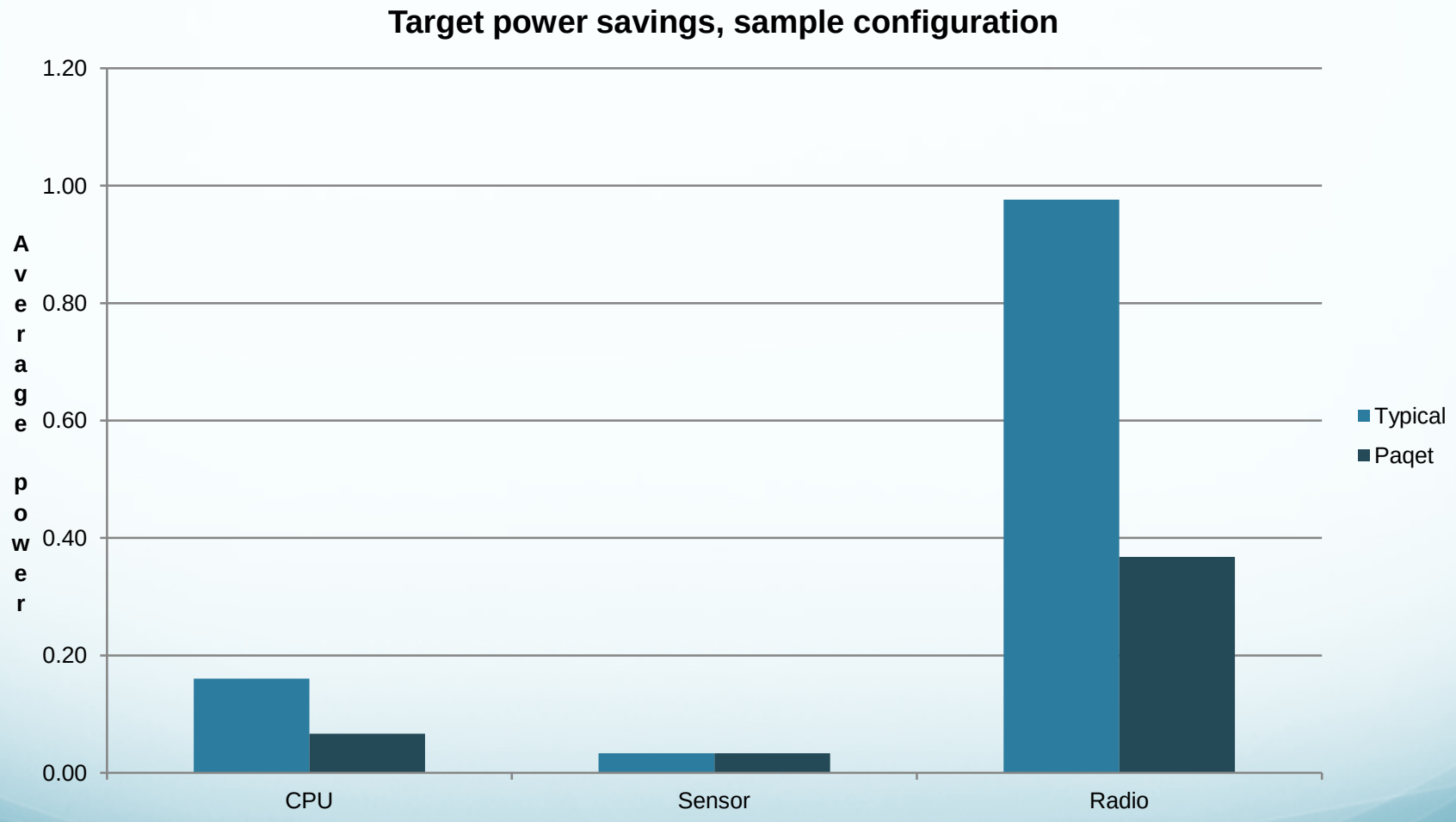
CPU: Deep sleep states, *Fast OS wake up*, Reflex, Leakage

Sensor management: Intelligence/hub

Use low power sensors most/first, e.g. accelerometer, temperature/ not Gyro

Event driven: OS decides whether sensor state demands radio wake up

Wireless Sensor Challenge: Reduce the radio duty cycle



Real IoT servers with minimum resources

NXP 810 (4K) ping

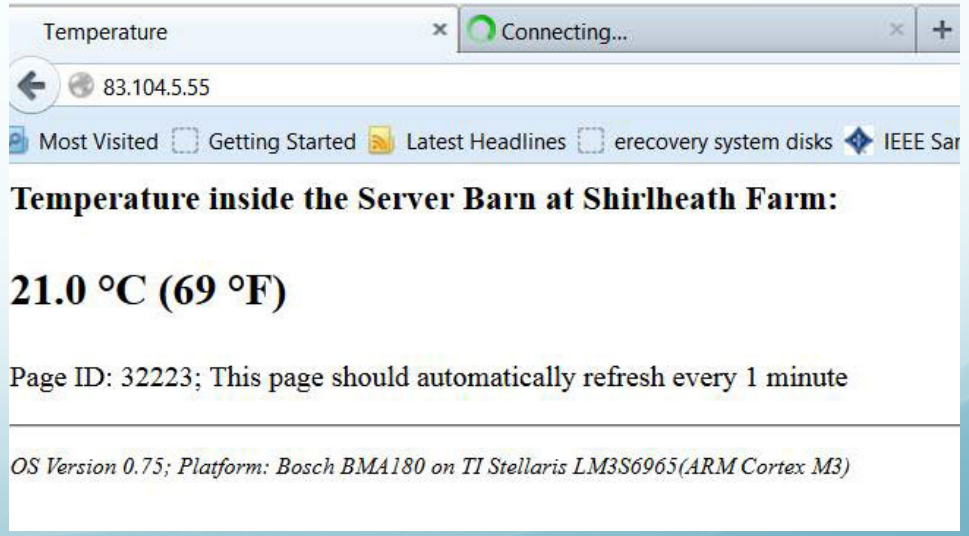
```
C:\>ping -t 83.104.5.56

Pinging 83.104.5.56 with 32 bytes of data:
Reply from 83.104.5.56: bytes=32 time=1025ms TTL=44
Reply from 83.104.5.56: bytes=32 time=1069ms TTL=44
Reply from 83.104.5.56: bytes=32 time=1070ms TTL=44
Reply from 83.104.5.56: bytes=32 time=1069ms TTL=44
Reply from 83.104.5.56: bytes=32 time=1071ms TTL=44
Reply from 83.104.5.56: bytes=32 time=1071ms TTL=44
Reply from 83.104.5.56: bytes=32 time=1069ms TTL=44
Reply from 83.104.5.56: bytes=32 time=1075ms TTL=44
Reply from 83.104.5.56: bytes=32 time=1072ms TTL=44

Ping statistics for 83.104.5.56:
    Packets: Sent = 9, Received = 9, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 1025ms, Maximum = 1075ms, Average = 1065ms
```

FRS M0+ with accel, via MQTT (8K)

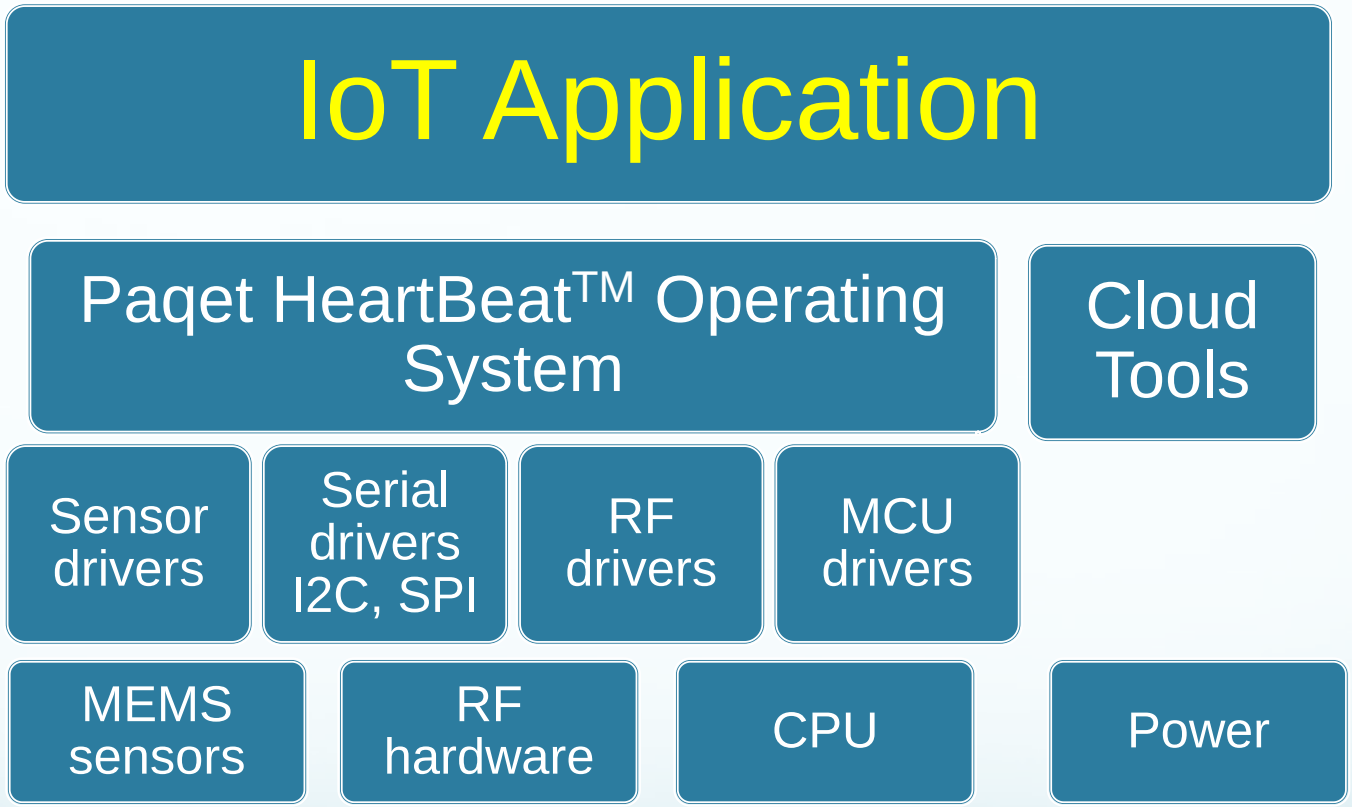
```
C:\>ping -t 83.104.5.50

Pinging 83.104.5.50 with 32 bytes of data:
Reply from 83.104.5.50: bytes=32 time=236ms TTL=43
Reply from 83.104.5.50: bytes=32 time=229ms TTL=43
Reply from 83.104.5.50: bytes=32 time=236ms TTL=43
Reply from 83.104.5.50: bytes=32 time=228ms TTL=43
Reply from 83.104.5.50: bytes=32 time=229ms TTL=43
Reply from 83.104.5.50: bytes=32 time=229ms TTL=43
Reply from 83.104.5.50: bytes=32 time=227ms TTL=43

Ping statistics for 83.104.5.50:
    Packets: Sent = 7, Received = 7, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 227ms, Maximum = 236ms, Average = 230ms
```

TI Cortex M3 with Bosch temp sensor (16K)

```
C:\>ping -t 83.104.5.55

Pinging 83.104.5.55 with 32 bytes of data:
Reply from 83.104.5.55: bytes=32 time=241ms TTL=44
Reply from 83.104.5.55: bytes=32 time=237ms TTL=44
Reply from 83.104.5.55: bytes=32 time=239ms TTL=44
Reply from 83.104.5.55: bytes=32 time=239ms TTL=44
Reply from 83.104.5.55: bytes=32 time=241ms TTL=44
Reply from 83.104.5.55: bytes=32 time=241ms TTL=44
Reply from 83.104.5.55: bytes=32 time=242ms TTL=44
Reply from 83.104.5.55: bytes=32 time=237ms TTL=44

Ping statistics for 83.104.5.55:
    Packets: Sent = 8, Received = 8, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 237ms, Maximum = 242ms, Average = 239ms
```



Virtual IoT Node Architecture



=> Paqet O/S allows Apps to be independent of all the hardware (CPU, Sensors, or Communications) allowing faster initial TTM, faster cost reduction, easy development of 3rd party IoT applications.

Advantage of modern design approach

Node hardware → System Software → Integration; application

~ 6 months each design

RTOS approach

MCU select
Sensor & RF design
Power supply
PCB, package

O/S hand crafting
O/S customization
Cloud software

Sensor I/F
RF & Comms I/F
Power mgmt code
Application code

~ 2 months first design, 1 month revision

Paqet approach

MCU select
Sensor & RF design
Power supply
PCB, package

O/S load including drivers and cloud

OTS drivers for sensor, RF, Comms, and Power mgmt
Application code

New IoT operating system

Thank You!

Steve Jordan