

# Analyzing Complex Systems

## The BlackBerry Case

FX of Phenoelit

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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?

# Step 1

---

Getting the big picture

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```



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# Why Big Picture?

---

- You might not know every aspect of the target
  - WYSIWYG is an intuitive but poor choice
  - WYSIWYG is probably where the focus of the defending side was
- The bigger the picture (system), the more clearly you need to identify the promising attack vectors
  - ... unless your organization has a three letter acronym and you got unlimited time on your hands

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# Why Big Picture? II

---

- You might not know what resources you will need
  - Hardware
  - Software
  - Infrastructure & Accounts
  - Tools
- Getting what you need might take time
- Trying to get it might have other consequences
  - Can you afford to invest money? How much?
  - Can you afford to cross legal lines?
  - Can you afford your target to know it's under attack?
  - Do you care?

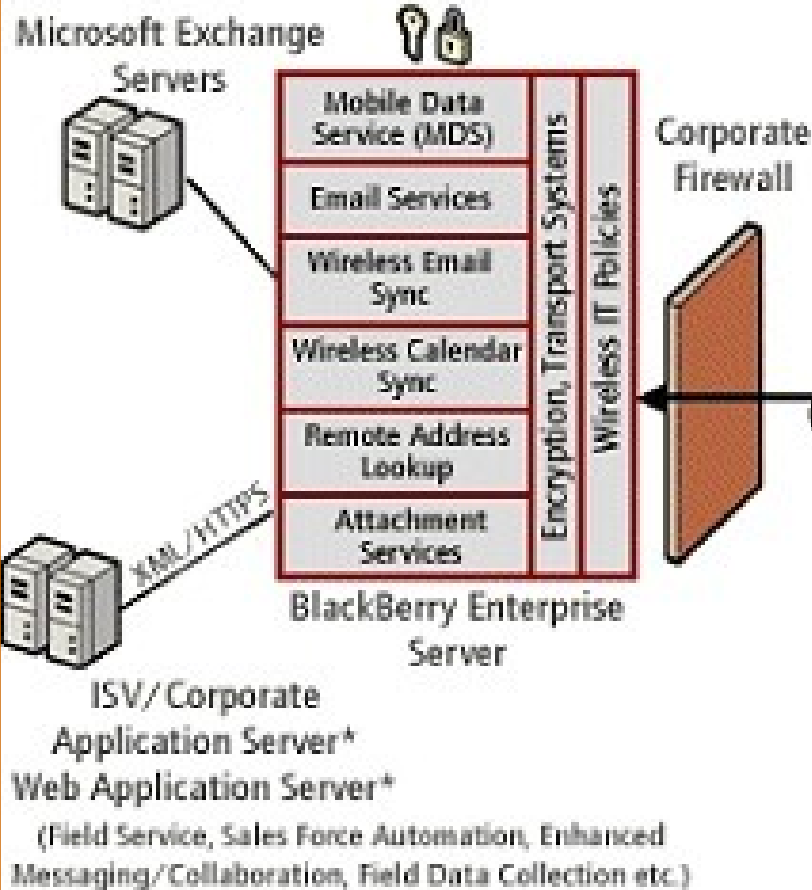
```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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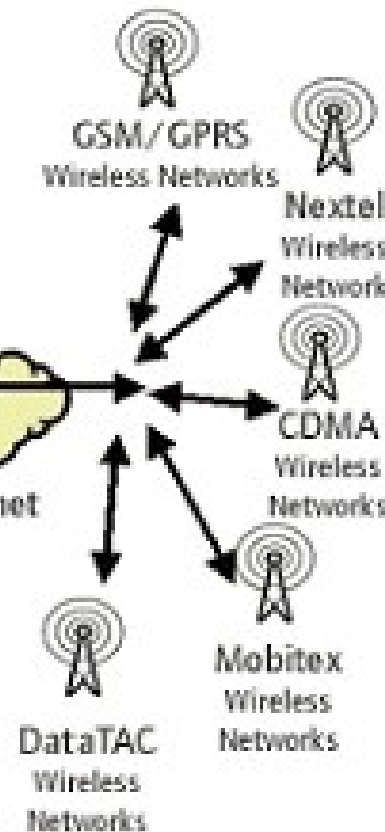


# Big Picture I

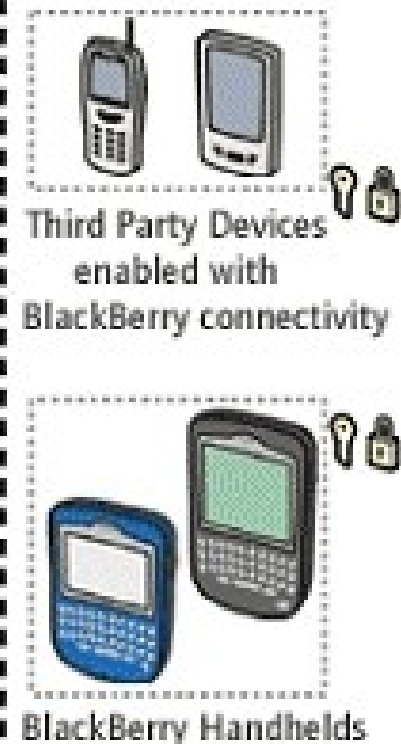
## Multiple Types of Data



## Multiple Networks



## Multiple Handhelds



\* Additional development may be required

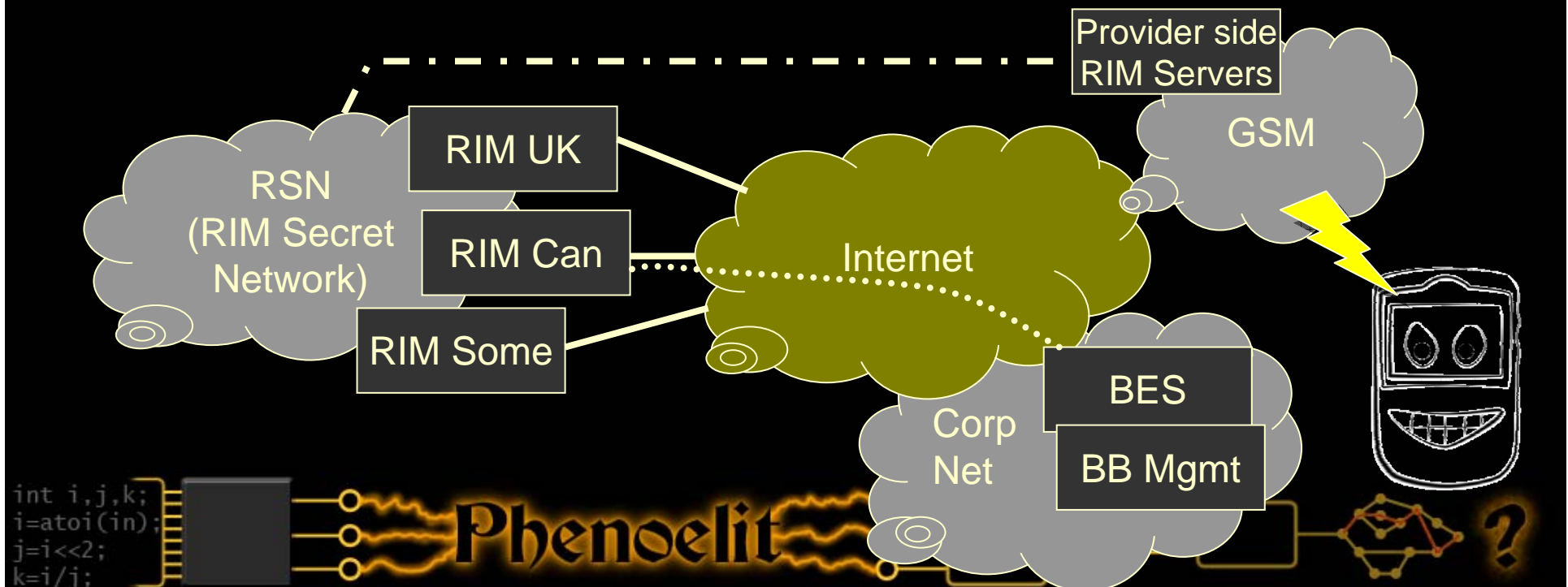
```
int i,j,k;
i=atoi(in);
j=i<<2;
k=i/j;
```

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# Big Picture II

- Abstraction of the big picture helps to identify key areas to look at
- Split the picture into it's major components



# Big Picture III

---

- Break down the primary components of the system you are looking at:
  - Handheld devices
  - Mobile Network (i.e. GSM)
  - RIM Network
  - Internet based communication
  - BlackBerry Enterprise Server
  - BlackBerry Enterprise Server Connectors
  - BlackBerry Management Tools

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# Big Picture IV

---

- Reclassify the key elements in common terms:
  - Handheld devices  
= Embedded system, proprietary hardware, RTOS, Java
  - Mobile Network  
= 2.5/3G GSM style infrastructure
  - RIM Network  
= unknown, likely IP based
  - Internet based communication  
= Proprietary IP based Protocols
  - BlackBerry Enterprise Server and Connectors  
= Windows based server software, closes source
  - BlackBerry Management Tools  
= Windows based client/server software

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# Big Picture V – Accessibility

---

- Accessibility of the components
  - Handheld devices
    - doable, \$666 per device
  - Mobile Network
    - hard, illegal
  - RIM Network
    - doable, illegal
  - Internet based communication
    - doable, requires access to a working installation
  - BlackBerry Enterprise Server and Connectors
    - easy, see IDA
  - BlackBerry Management Tools
    - easy, see IDA

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# Big Picture VI – Impact

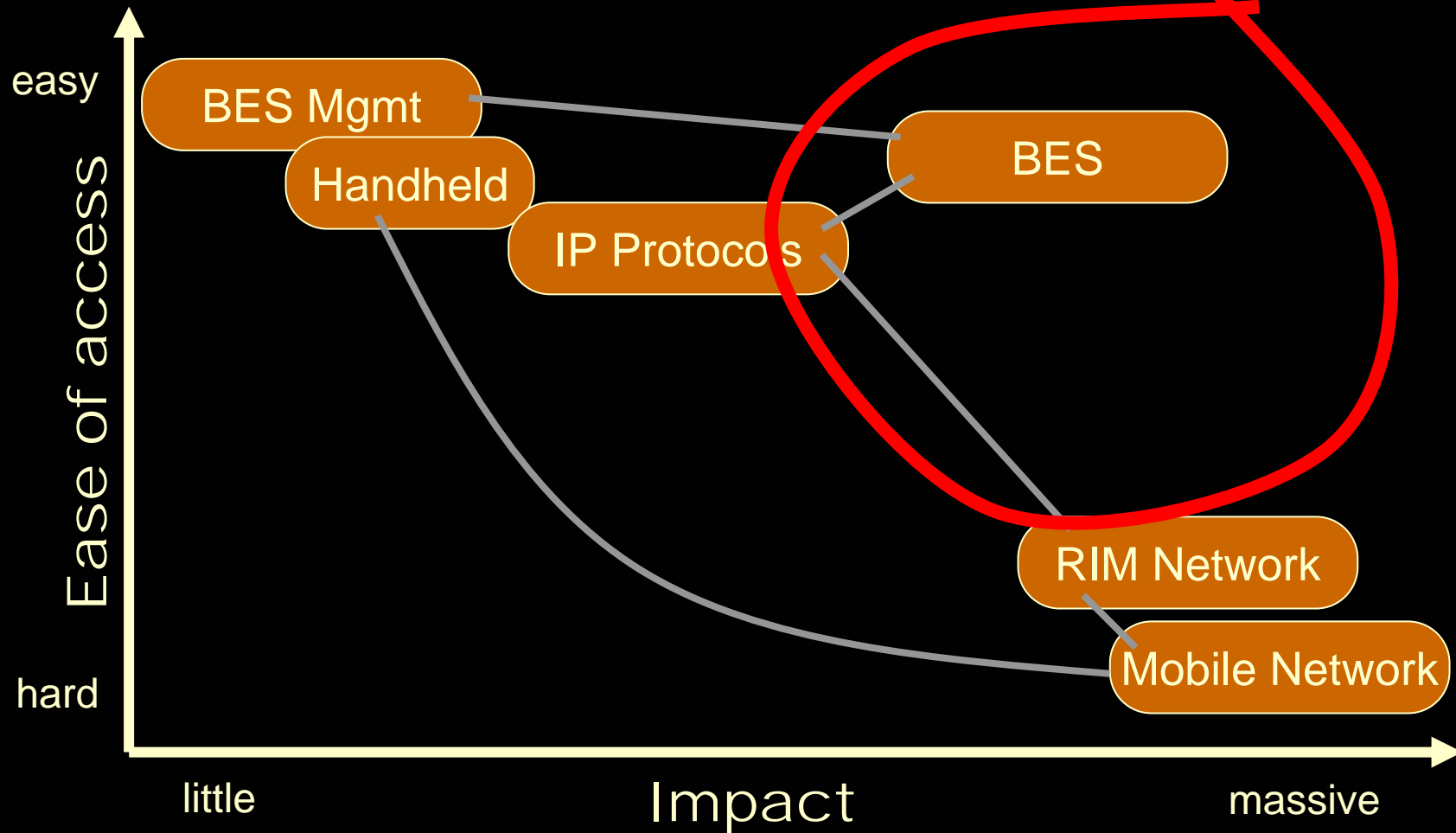
- Estimate the impact of a successful attack
  - Handheld devices
    - Information disclosure, potentially remote control of single user
  - Mobile Network
    - Redirection of communication endpoints
  - RIM Network
    - Full control over the infrastructure, being RIM
  - Internet based communication
    - Impersonation of RIM or BlackBerry Server, brute force attacks
  - BlackBerry Enterprise Server and Connectors
    - Code execution on host OS, owning of a centrally placed server system in corporate networks
  - BlackBerry Management Tools
    - Modification of policies, sending messages to everyone, may be installing software on handhelds (see Handheld devices)

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# Big Picture VII



```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```



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# Step 2

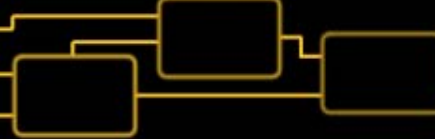
---

Getting the details right

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```



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# Diving into Details

---

- When you got the big picture completed, the details are what matters most
- The details decide:
  - How hard it will be to find an attack
  - What you need
  - How feasible the attack is
  - How (il)legal the attack is

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# Handheld devices

---

- Simulation environment available
- Developer SDK available
  - Current version is for Java
  - Old version is for C
    - Obviously more interesting (no sandbox)
    - Only available for US and Canadian developers
- Desktop Software available
- Third party code available
  - What do the 3rd party products do?
  - What does this tell you about the powers of the API?

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# Protocols

---

- How many communication channels are used?
- Who initiates the communication, who can?
- What underlying protocols are used (i.e. are they connection oriented or connection-less)?
- How much encapsulation is used?
  - Multiple levels of encapsulation indicate a tree structure of code handling the payload.
  - Flat protocols indicate a single massive protocol parser.
- How variable is the protocol design?

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# Server Software

---

- How is the software designed?
  - User-land, Service or Kernel?
  - Security Context and required privileges?
- What building blocks is the software made of?
  - Which handle user input?
  - How is the user input transformed before handled by this component?
  - Who developed the component?
  - What coding style was used?
  - What programming language was used?
  - Where is the interesting stuff stored?

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# Things to look at for details:

---

- History

- How old is the component compared to the overall scenario?
- Where does this component come from? What did the first release do, what does the latest?
- Was there any major rewrite?
- Check the press releases.

- Documentation

- What are the setup requirements in administration guides?
- What are the troubleshooting procedures recommended?
- What are the troubleshooting procedures people actually use?

→ Take what you read in publications, press releases, documentation and forums as a hint, not a fact!

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# Step 3

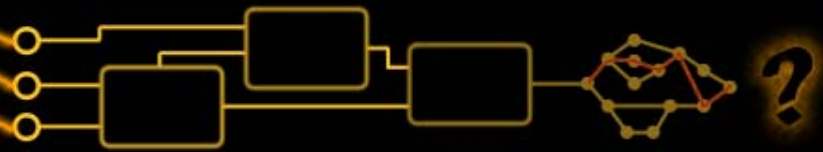
---

## Work

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```



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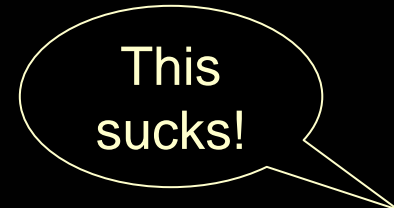
?

# Work...

---

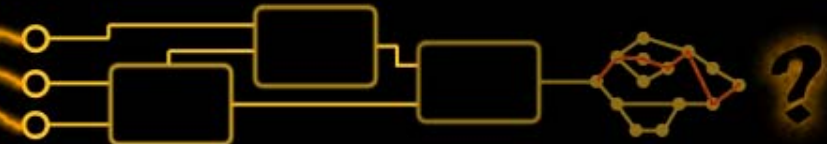


1 hour  
20 hours  
30 hours  
40 hours  
50 hours  
100 hours  
200 hours  
300 hours  
400 hours  
500 hours...



```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# Step 4

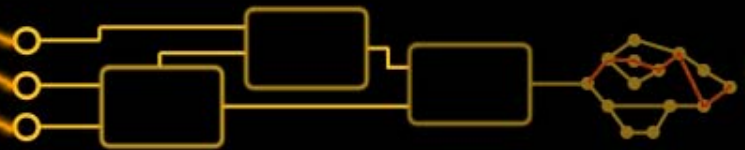
---

## Results: The Handheld

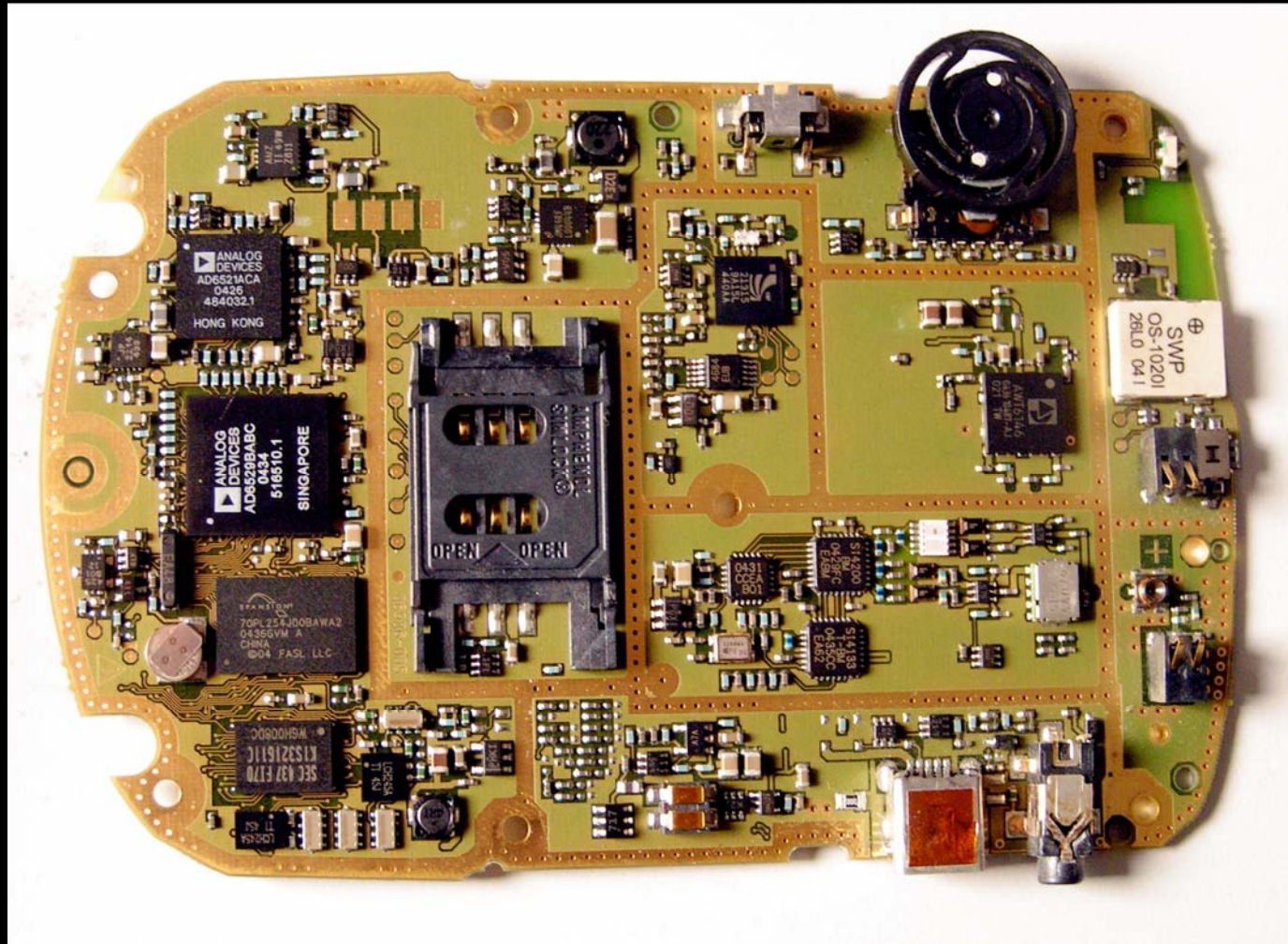
```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```



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# First things first: strip it !



7290 naked  
(back view)

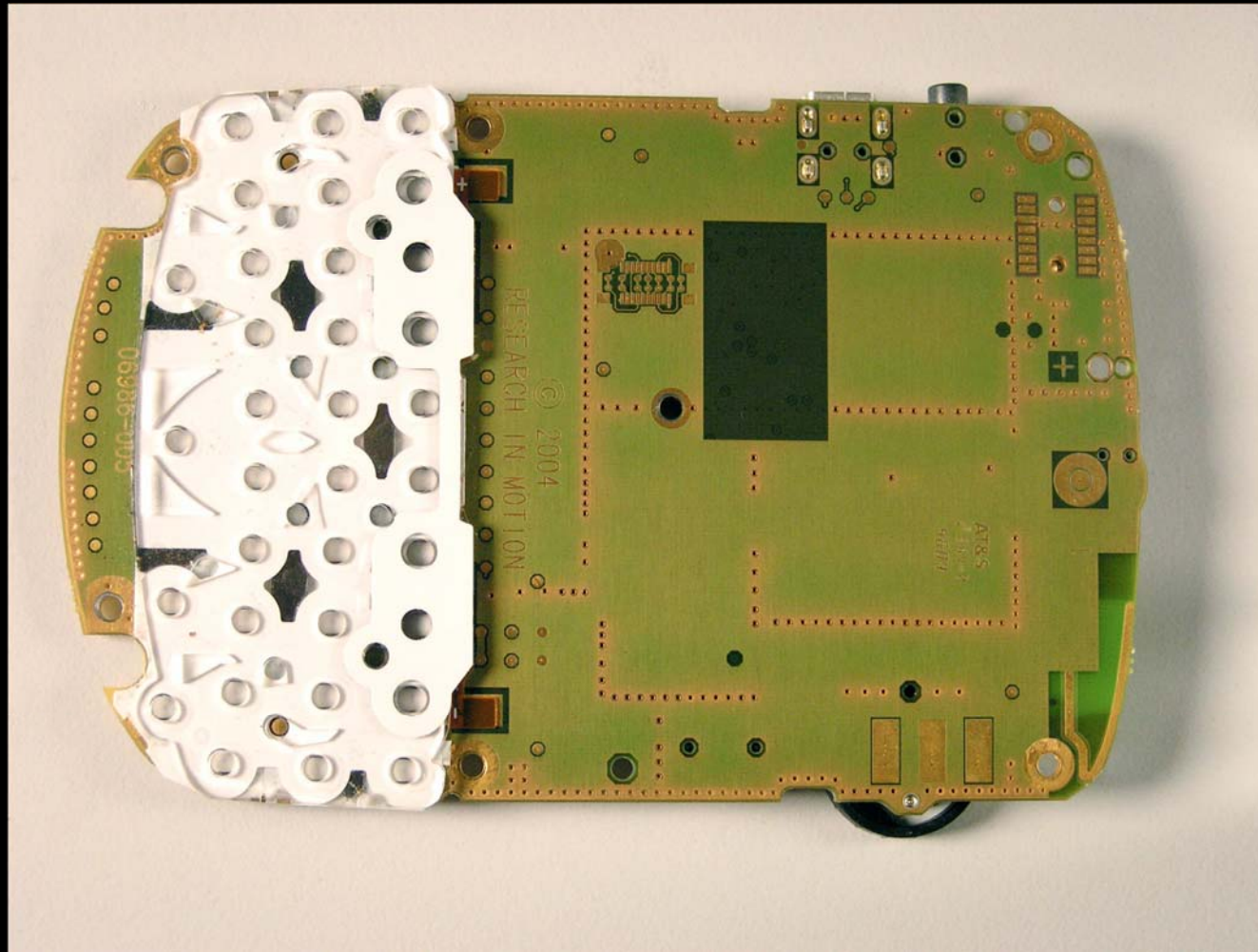
```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# First things first: strip it more!



7290 naked  
(front view)

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# Handhelds

- Used to be 386, turns out it's an ARM (C SDK fairly useless since it's for 386)
- Different RTOS Kernels, some run KADAK AMX 4, others run RIM proprietary code. Every model is different.
- Binary images with hardware near code
- Loadable modules as PE/COFF DLLs linked against the RIMOS.EXE main binary



```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# Handheld JVM

---

- Java Virtual Machine loaded as largest binary module (jvm.dll)
  - CDLC 1.1, MIDP 2.0
  - Java Vendor is RIM
- Limited set of J2ME classes
  - Reflection API missing ☹
- Device control via RIM classes
  - Java applications are almost useless without RIM class support

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# Code Signing

---

- Java Application signature
  - To use RIM classes
  - Signs a hash of the JVM binary (.jar)
  - \$100 to be paid by credit card
  - Suspicion: Collection of a list of all platform binary's hashes in case they become malware
  - News Flash: Stolen Credit Cards exist
  - Replacing the class loader doesn't work ☹
- Firmware image signature
  - Checked in Loader (see your debugger ☺)
  - Something is checked while device is loading ☹

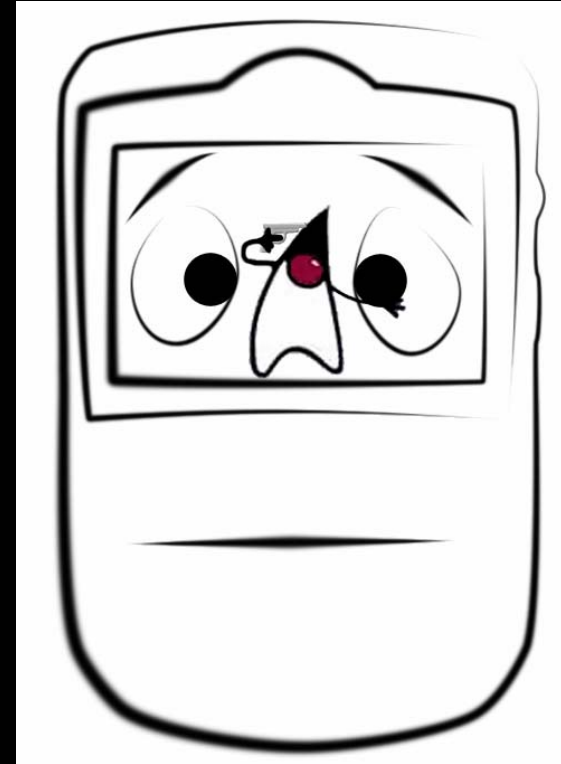
```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# It's not a Siemens, but ...

- Browser Issue when parsing .jad Files:  
long name for MIDlet-Name or -Vendor
  - Exception thrown by the dialog
  - Uncaught, modal dialog left over
  - Browser toast, everything else still works
  - Soft- or Hard-Reset don't work (solution: denial all power to the device)
- RIM says it's fixed in 4.0.2



```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# Other things not tried yet

---

- Find the JTAG connectors
- Bluetooth on BlackBerry
- JVM bugs
- Reversing Images
- Figuring out checksums
- Loader.exe should be able to read memory contents from the device as well  
(credit: mark@vulndev.org)

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# Step 5

---

## Results: The Protocols

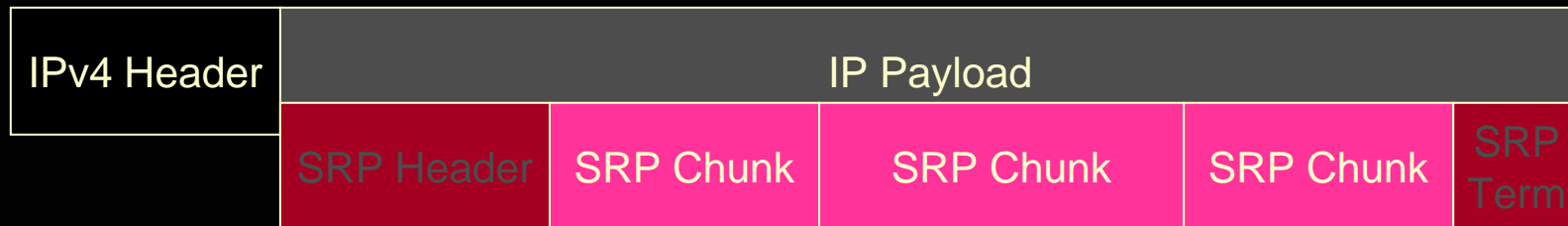
```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# Server Relay Protocol

- Encapsulation protocol inside IPv4
  - Simple header
  - Multiple string or integer payload chunks in TLV (type, length, value) format



```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# Server Relay Protocol

## Header

Byte	Meaning
1	Protocol Version
2	Function
3-6	Length of the entire message

## Chunk Format

Data type	Byte	Value/Meaning
String	1	0x53 / type identifier
	2-5	/ length of the string
	6-x	/ content
Integer	1	0x49 / type identifier
	2-5	/ value

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# SRP Opcodes

---

- 01 - RETURN
- 02 - DISCONNECT
- 03 - RECEIVE
- 04 - STATUS
- 05 - SEND
- 06 - CONNECT
- 07 - REGISTER
- 08 - DATA
- 09 - PAUSE
- 0A - RESEND
- 13 - CANCEL
- 14 - STATUS\_ACK
- 15 - SUBMITTED
- 18 - DATA\_ACK
- 19 - RESUME
- 21 - STATE
- F0 - RESET
- F1 - INFO
- F2 - CONFIG
- FC - PING
- FD - PONG
- FE - SRP Error

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# Session Setup

---

1. Client → Server: System ID
2. Server → Client: Server challenge
  - Server Random seed + Random value + Ctime
3. Client → Server: Client challenge
  - Client Random seed + Random value + Service string
4. Server → Client: HMAC\_SHA1 (Client challenge)
  - Transformed SRP Key used for HMAC\_SHA1
5. Client → Server: HMAC\_SHA1 (Server challenge)
6. Server → Client: init request
7. Client → Server: init data

Successfully implemented a Server and a Client in Perl

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

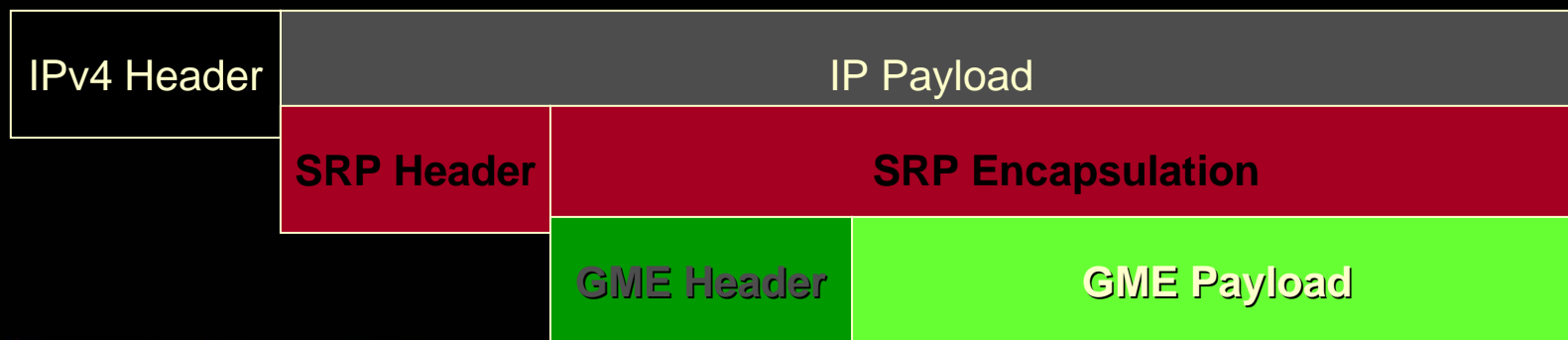
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# Gateway Message Envelope

- Encapsulation protocol for messaging
- Routing Information of the message
  - Source (Server Identifier or PIN)
  - Destination (Server Identifier or PIN)
  - Message ID
- Comparable to information in Email headers



```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# Generic Message Encapsulation(?)

**GME Format**

Field	Format
Protocol version	1 byte
Source	Type = 1 byte [0x10] Length = 1 byte Value
Destination	Type = 1 byte [0x20] Length = 1 byte Value
Terminator	1byte = [0x00]
Message ID	4 byte
Application Identifier	Type = 1 byte [0x50] Length = 1 byte Value
GME command	1 byte
Content length	Variable length integer
Terminator	1byte = [0x00]

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# Application Layer

---

- Application layer identifier in clear text
  - CMIME = message
  - CICAL = calendar updates
  - ITADMIN = key updates, IT policies, etc.
- Email, calendar and others encrypted
- PIN messages in clear text
  - Documented behavior, but very hard to find

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# Application Layer

---

## CMIME Format

Field	Format
Encryption Type	1 byte
Key ID	
Terminator	1 byte [0x00]
Session Key	32 Byte
Terminator	1 byte [0x00]
Message identifier	1 byte [0x19]
Message	

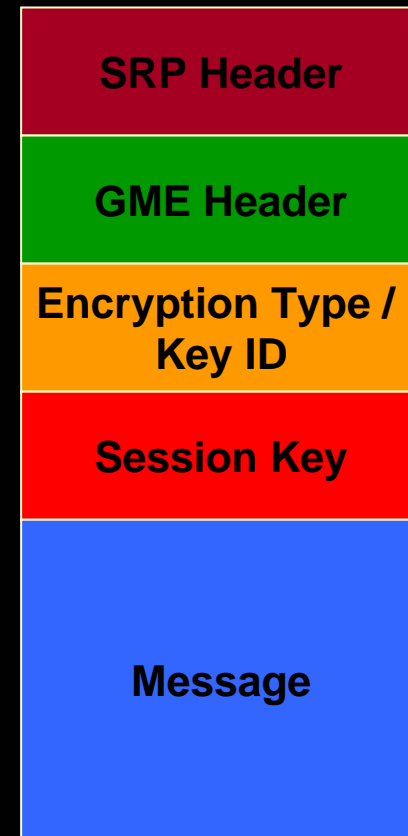
```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# Application Layer Payload

- AES or DES encryption
- Key ID in clear text
- Session Key encrypted with device key
- Message compressed and encrypted with session key
- Successfully implemented packet dump message decryption script with given key in Perl



```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# A word about the crypto

---

- Crypto library is FIPS certified
- Phe-no-crypto-people
- Implementation looks good in the disassembly
- No obvious key leak problems when activating devices via USB
- Crypto may be re-Weis-ed (as in Rüdi)

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# Decoding Dumps

0000000:	0208	0000	0083	4900	0002	f953	.....I....S
000000c:	0000	006f	2010	0954	3636	3632	...o ..T6662
0000018:	3334	3236	2008	3233	3233	3233	3426 .232323
0000024:	3233	0000	000c	3850	0543	4d49	23....8P.CMI
0000030:	4d45	0340	4a00	0230	2b47	2b62	ME.@J..0+G+b
000003c:	001f	5131	9943	34ba	e60e	f8e4	..Q1.C4.....
0000048:	1b9e	94e5	62c7	38ac	91dc	c88a	...b.8.....
0000054:	ba93	6edf	1e32	6732	b800	19e7	..n..2g2....
0000060:	1d40	d58b	0fbc	eca3	0395	168c	..@.....
000006c:	ddb8	b66e	501a	1f08	9d5e	93b7	...nP....^..
0000078:	3d07	475c	4115	6149	0000	0000	=.G\A.aI....
0000084:	4900	0000	0300	00			I.....

SRP

GME

Encrypt Hdr

Key

Message

```
int i,j,k;
i=atoi(in);
j=i<<2;
k=i/j;
```

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# Traffic analysis

---

- Traffic analysis based on header possible
  - Sender PIN known
  - Recipient PIN known
  - Message content type known
  - Timing known
- In combination with (il)legal interception of SMTP email traffic
  - Email address to PIN mapping

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# Protocol based attacks I

---

- SRP Session setup with someone else's key and SRP ID
  - Legitimate key owner disconnected when modifying data in the session startup
  - New connection from either source results in the other one begin dropped
    - After 5 reconnects in less than a minute, the key is locked out. No BlackBerry service until RIM resolves the issue.
- RIM Authentication keys are not viewed as secrets by most companies
  - Slides and screenshots with keys can be found by your favorite search engine

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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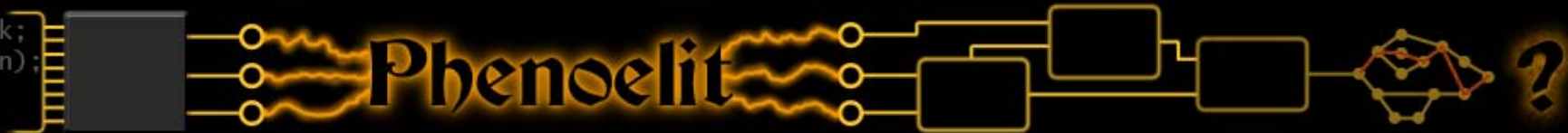
# Protocol based attacks II

- SRP String Type length field
  - Integer overflow leads to Access Violation when initially decoding packets
  - Negative value -5 causes infinite decoding loop
  - Affects at least router and enterprise server

```
.text:0042B11B      OR          eax, edx
                  ; EAX is length field (now in Host Byte Order) after \x53
.text:0042B11D      LEA        edi, [eax+ecx]
                  ; ECX is current position pointer in packet
.text:0042B120      CMP        edi, ebx
                  ; position + length > overall_length ?
.text:0042B122      JG         short loc_42B19F
                  ; jump to failure handling code if position + length points
                  ; past the packet
```

```
int i,j,k;
i=atoi(in);
j=i<<2;
k=i/j;
```

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# Spam anyone?

- PIN messages not encrypted
  - Therefore, no crypto code needed
- SRP authentication key can be used to PIN message anybody, not only your users
  - Any legitimate or stolen SRP key can be used
- Simple Perl script sufficient to send messages to any PIN
  - Sequentially sending it to all PINs from 00000000 to FFFFFFFF ?
  - Spoofing sender might be possible (no evidence that it is not) – turns out it is!



```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# Step 666

---

Results: The Enterprise Server

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# BlackBerry Enterprise Server

---

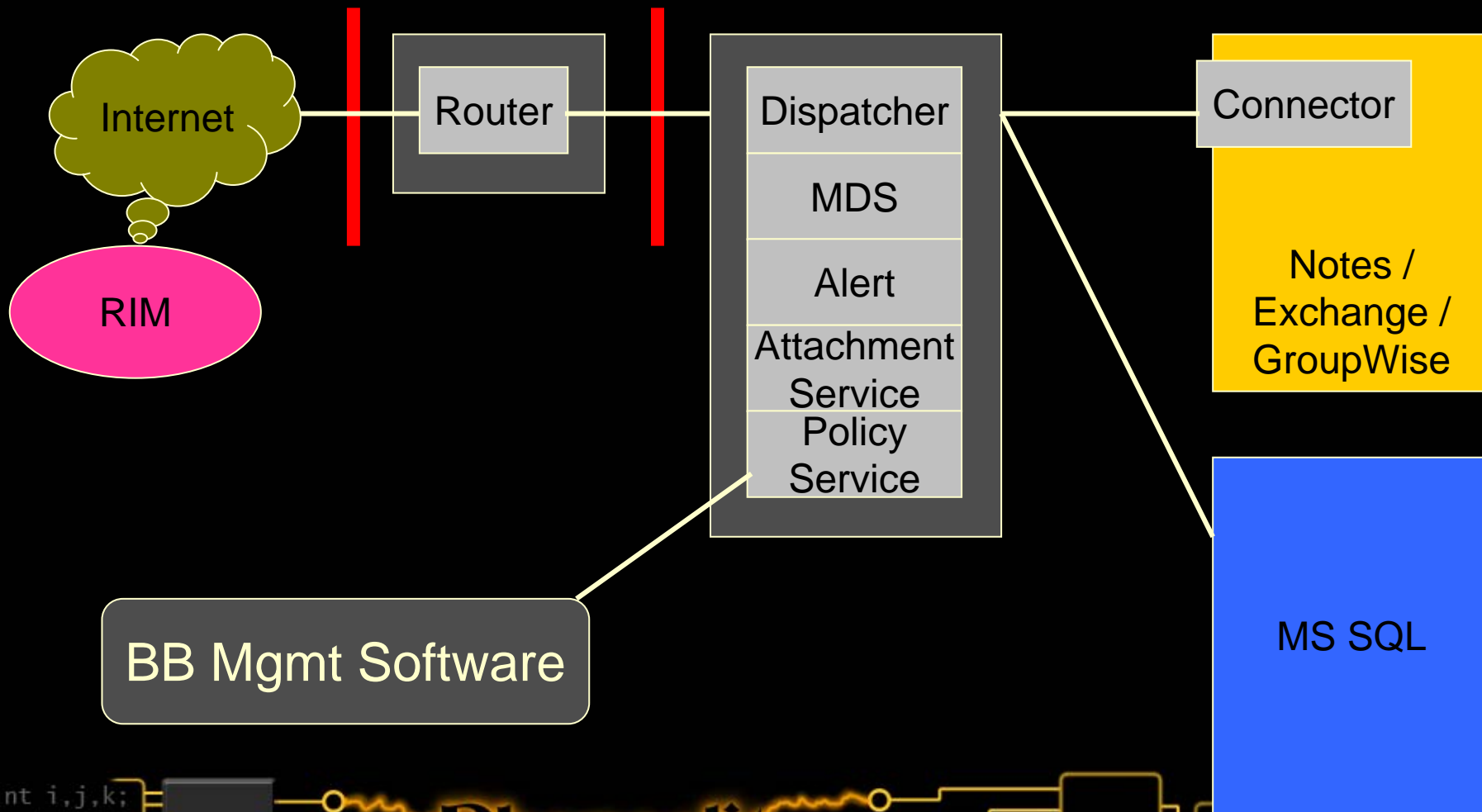
- BES Architecture
- SQL Database
- The beauty of updates
- Code style and quality
- Interesting libraries
- Attachment Service Special

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# BES Architecture



```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# BES Accounts

	Logon Locally	Logon as Service	Local Admin	Exchange RO Admin	Exchange MailStore Admin
Service Account	✓	✓	✓	✓	✓
Server Mgmt Account	✓	✓	✓	✓	✓
User Admin Account		✓	✓	✓	

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# SQL Database

---

- MS SQL Server with user authentication
  - No integrated authentication for Domino
- Tables for individual messages and mails
- Table with SRP Authentication Key
  - The most important secret between the BES and RIM stored in clear text
- Table with Device Keys
  - Previous, current and new/pending key
  - Can be used for traffic decryption
- Default account: SA / (no password)

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# The beauty of updates

---

- RIM updates the BES
  - Service Packs
  - HotFixes
  - Release and fix notes tend to be extremely entertaining
- Hackers should update BES
  - SABRE BinDiff
  - Free .pdb debug information files in some fixes. Many thanks to RIM.

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# Code style & quality

---

- Massive C++ code
  - By-the-book pattern implementations
  - Large classes
  - STL
  - Harder to reverse engineer
- Surprisingly good
  - STL helps a lot
  - “If in doubt, check again” approach
    - A.k.a. select, select, select, recv
  - But generally using signed integers, although mostly correct

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# Interesting Libraries – reverse engineered

---

- Microsoft IStream classes
  - Parsing of Microsoft Office documents
- Microsoft MSHTML4 engine
  - Parsing of HTML documents
- MSXML SDK
  - Installed, no idea what for.
  - MSXML used for Sync server.
- Arizan parsing product
  - Central parsing engine
  - Parsing of PDF and Corel WordPerfect

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# Interesting Libraries – reverse engineered

---

- Zlib 1.2.1
  - ZIP attachment handling is copy & paste contrib/unzip.c (almost binary equal)
  - Known bugs 😊  
1.2.3 is current
- GraphicsMagick 1.1.3
  - ImageMagick spin-off
  - Fully linked, including debug code and ...

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# open source → source audited

---

- ...supported and compiled in file formats in GraphicsMagick:
  - ART, AVI, AVS, BMP, CGM, CMYK, CUR, CUT, DCM, DCX, DIB, DPX, EMF, EPDF, EPI, EPS, EPS2, EPS3, EPSF, EPSI, EPT, FAX, FIG, FITS, FPX, GIF, GPLT, GRAY, HPGL, HTML, ICO, JBIG, JNG, JP2, JPC, JPEG, MAN, MAT, MIFF, MONO, MNG, MPEG, M2V, MPC, MSL, MTV, MVG, OTB, P7, PALM, PBM, PCD, PCDS, PCL, PCX, PDB, PDF, PFA, PFB, PGM, PICON, PICT, PIX, PNG, PNM, PPM, PS, PS2, PS3, PSD, PTIF, PWP, RAD, RGB, RGBA, RLA, RLE, SCT, SFW, SGI, SHTML, SUN, SVG, TGA, TIFF, TIM, TTF, TXT, UIL, UYVY, VICAR, VIFF, WBMP, WMF, WPG, XBM, XCF, XPM, XWD, YUV

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# Source audit: Use the Code Luke !

---

- GraphicsMagick ChangeLog:
  - “coders/avi.c, bmp.c, and dib.c: applied security patch from Cristy.”
  - “coders/tiff.c (TIFFErrors): Prevent possible stack overflow on error.”
  - “coders/psd.c (ReadPSDImage): Fix stack overflow vulnerability”
  - “coders/tiff.c (ReadTIFFImage): Fix overflow while computing colormap size.”
- Odd own format strings in arbitrary text fields of any image format
  - Expect image comment `100%tonne` to become `100C:\Windows\temp\bbaAA.tmponne`

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# Reverse Engineering + Source results I

---

- Heap overflow in TIFF parser
  - Integer overflow in image data memory requirement allocation
  - Allocation of small (0) memory block for image data

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# Reverse Engineering + Source results II

---

- Heap overflow in PNG parser
  - `#define PNG_USER_WIDTH_MAX 1000000L` does not prevent integer overflows
  - Overflow in memory allocation counter
  - Allocation of small (1MB) memory block for image data decompression

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# More Open Source results

---

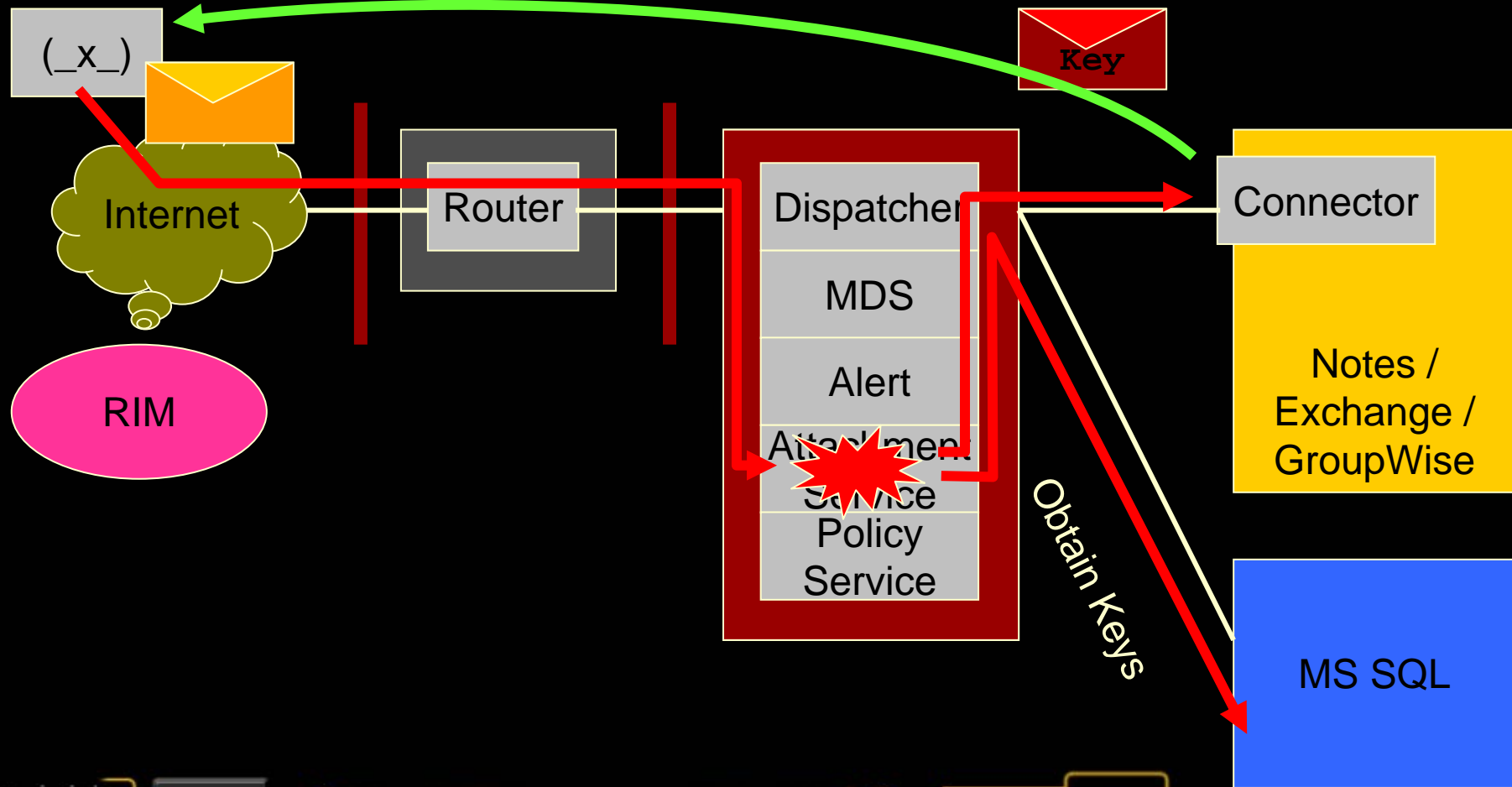
- Zlib museum in PNG parser
  - Paying attention?  
Version 1.2.1 used, inclusive decompression bug
  - PNG image data is zip compressed
  - Heap overflow when decompressing image data
  - Your arbitrary BugTraq example works
- Interestingly enough, known libPNG bugs are fixed

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# BES Architecture Attack

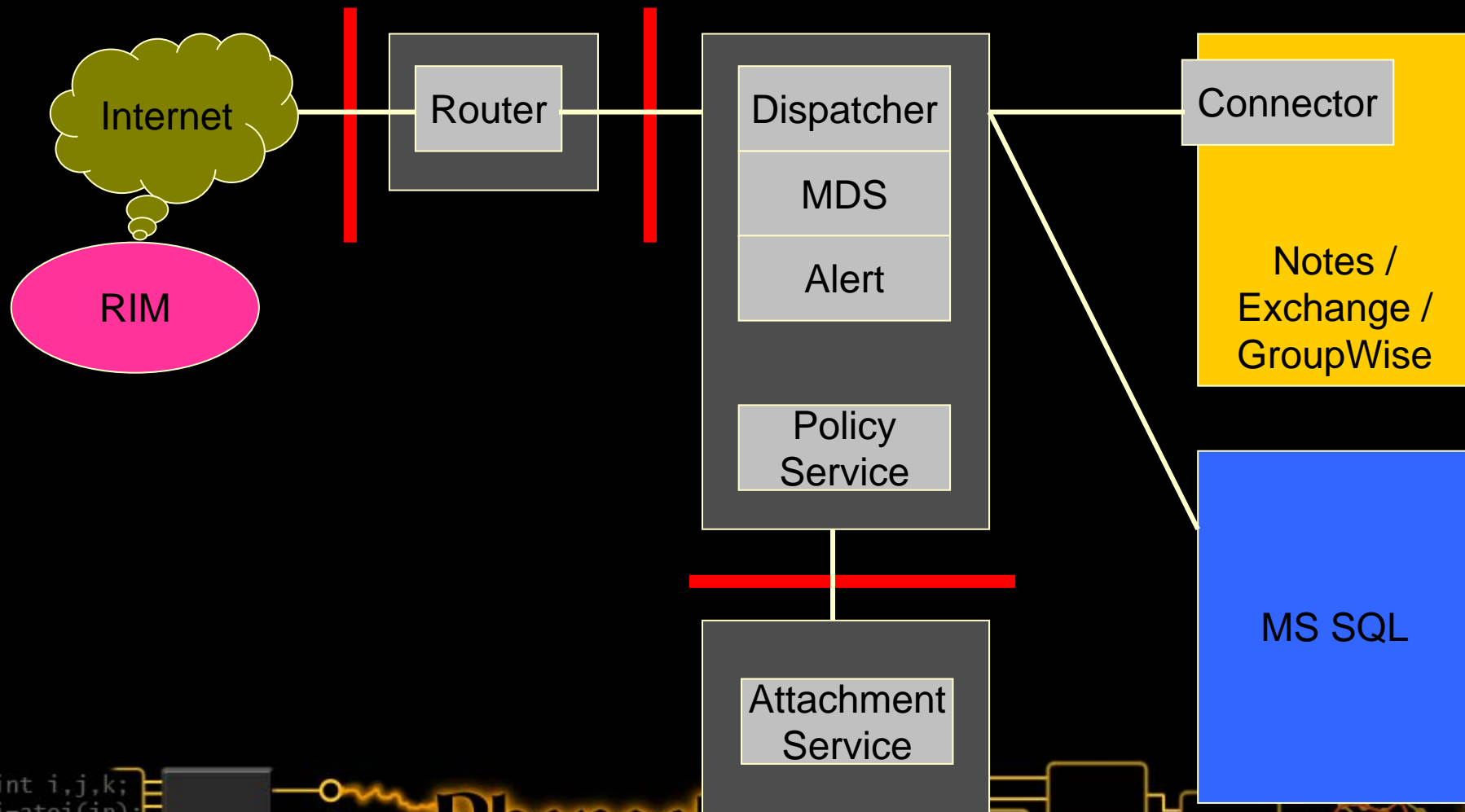


```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# BES Architecture must be



```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# Separate Attachment Service issue

---

- Remote control
  - TCP port 1999
  - Unauthenticated XML
  - Query
    - Version
    - Statistics
    - Number of processes
  - Set number of processes
    - Recommended test values: 0, 20000

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# Step 7

---

## Mopping up

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```



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# Vendor communication

---

- Vendor and users of the system in question can greatly profit from the analysis done
  - Well planned analysis yields unique insights in the architecture and the effectiveness of fixes
- RIM
  - re-work of attachment image parsing
- RIM customers
  - Moving BES and Database in separate DMZ
  - Separation of the attachment service

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

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# Finalizing

- Print offensive T-Shirts
- Meet with everyone involved
- Get drunk
- Send greets to random people, such as:



**Phenoelit, 13354, Halvar Flake & SABRE Security, THC, all@ph-neutral, hack.lu, Scusi, mark@vulndev.org, Frank Rieger, the Eschschloraque Rümpschrümp, mac, t3c0, trash, the darklab@darklab.org people and Ian Robertson from RIM**

```
int i,j,k;  
i=atoi(in);  
j=i<<2;  
k=i/j;
```

**Phenoelit**

