Automated Test Case Generation from P4 Programs

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The Need: Test any arbitrary protocol, conveniently, at line rates

Programmable Data plane (exemplified by P4)

THE NEXT STEP IN SDN

P4 Enables:

- ✓ Protocol Independence
- ✓ Handle existing and future protocols
- ✓ Target Independence
- ✓ Line-rate processing

PROBLEM: How do you test a new protocol with existing line-rate testers?

☹ new protocols not standardized yet, are experimental or proprietary

☹ tools don't generally anticipate unknown protocols, or else handle them inadequately

SOLUTION:

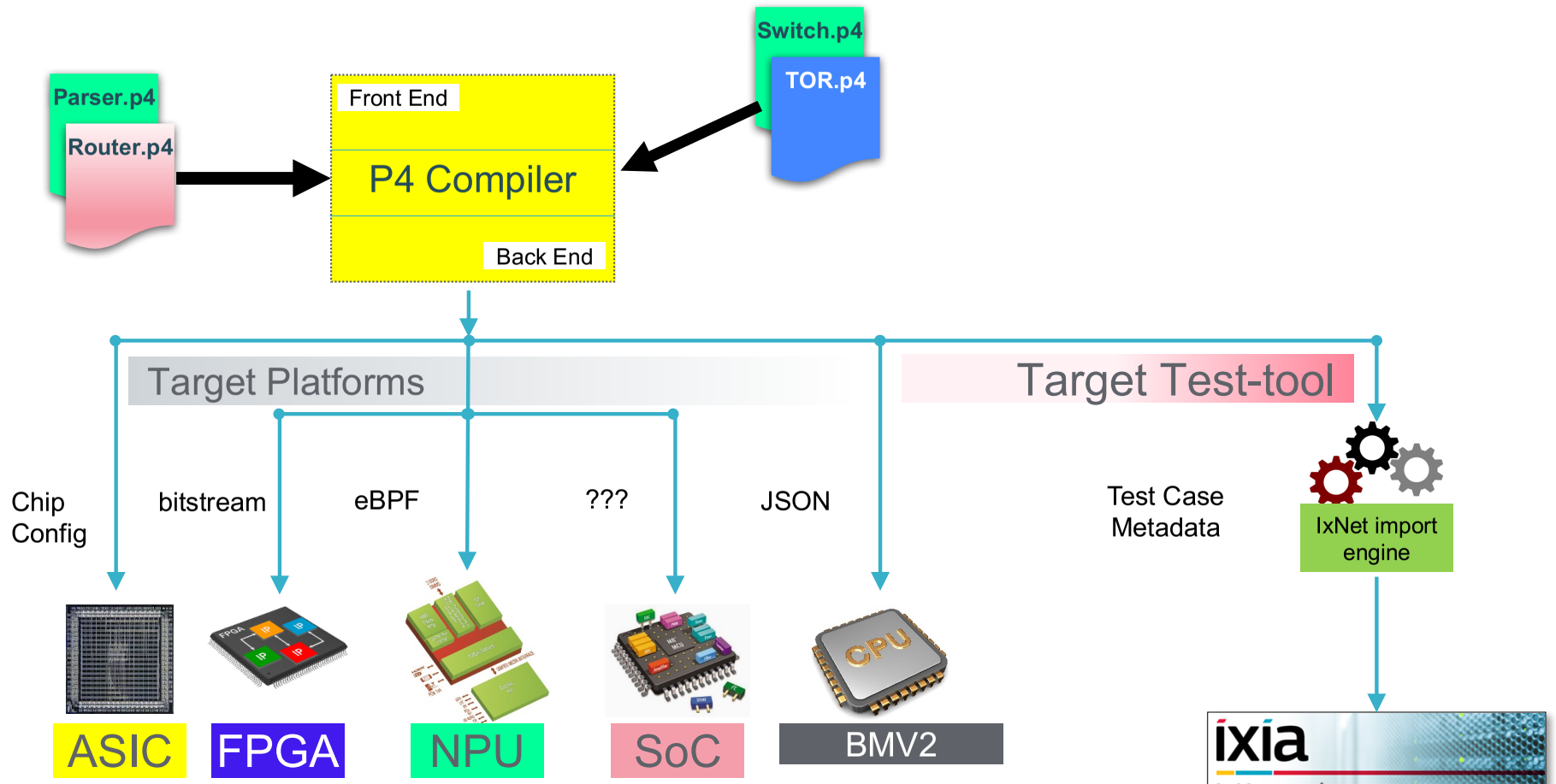
The P4 code which defines the function of a device, can also act as the **specification for the test-tool**.

Thus we can achieve a protocol-independent "protocol test tool". *

KEYSIGHT TECHNOLOGIES

* Keysight has HW based tools for data plane testing

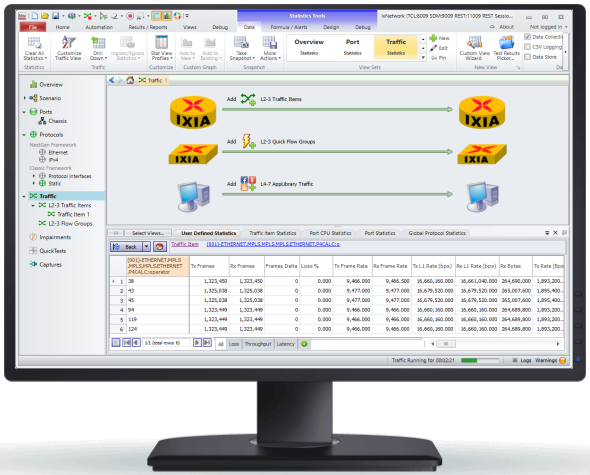
WORKFLOW



KEYSIGHT TECHNOLOGIES

Overview of IxNetwork

IxNetwork + Physical Test Chassis

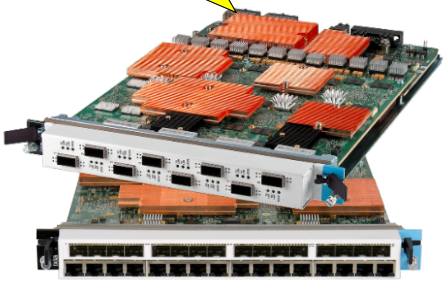


Test Console /IxNetwork Client

Test Control

Ixia Chassis

Packet Engine

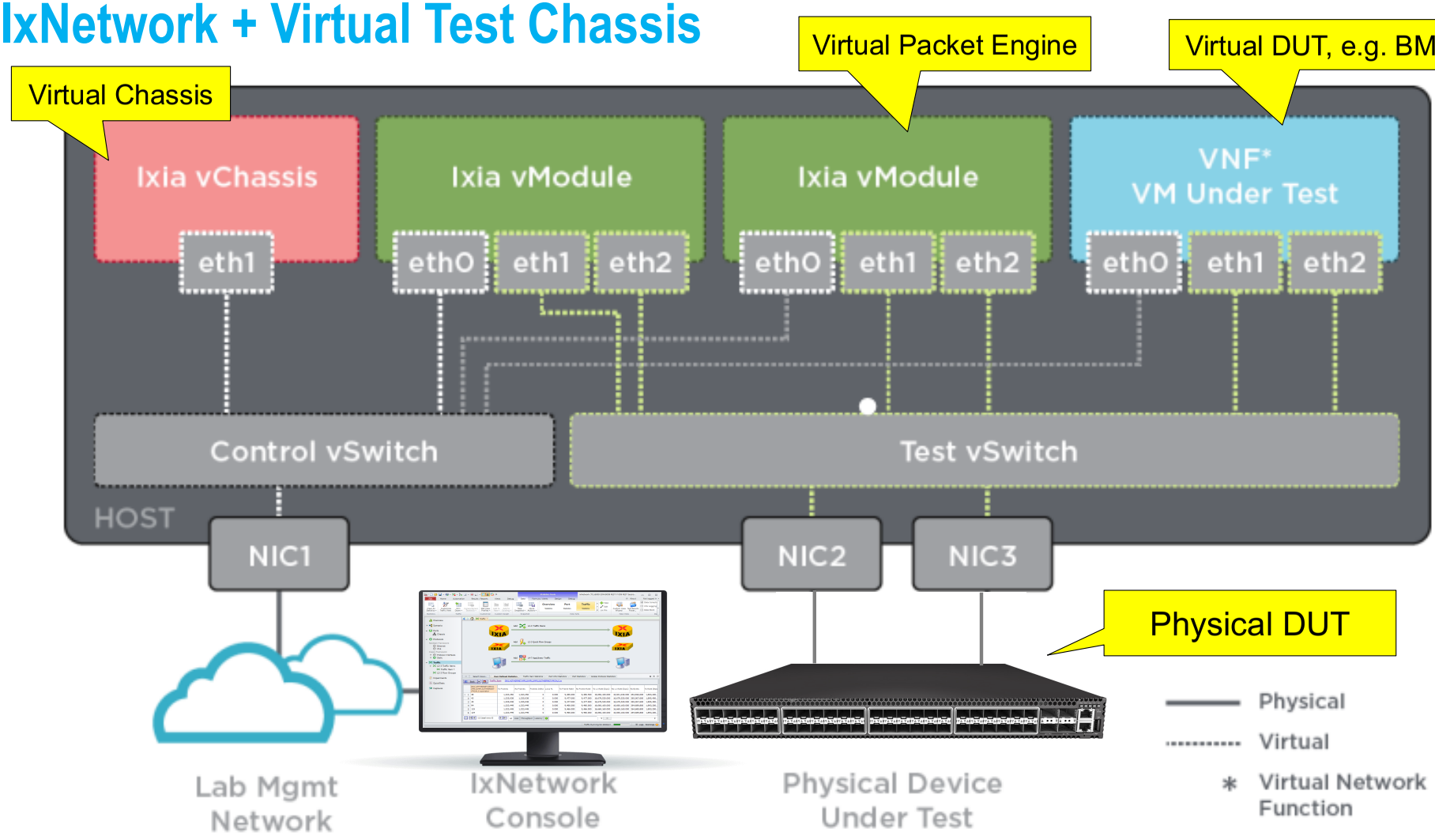


Load Modules
Up to 400GbE

Traffic

Device Under Test (DUT)

IxNetwork + Virtual Test Chassis

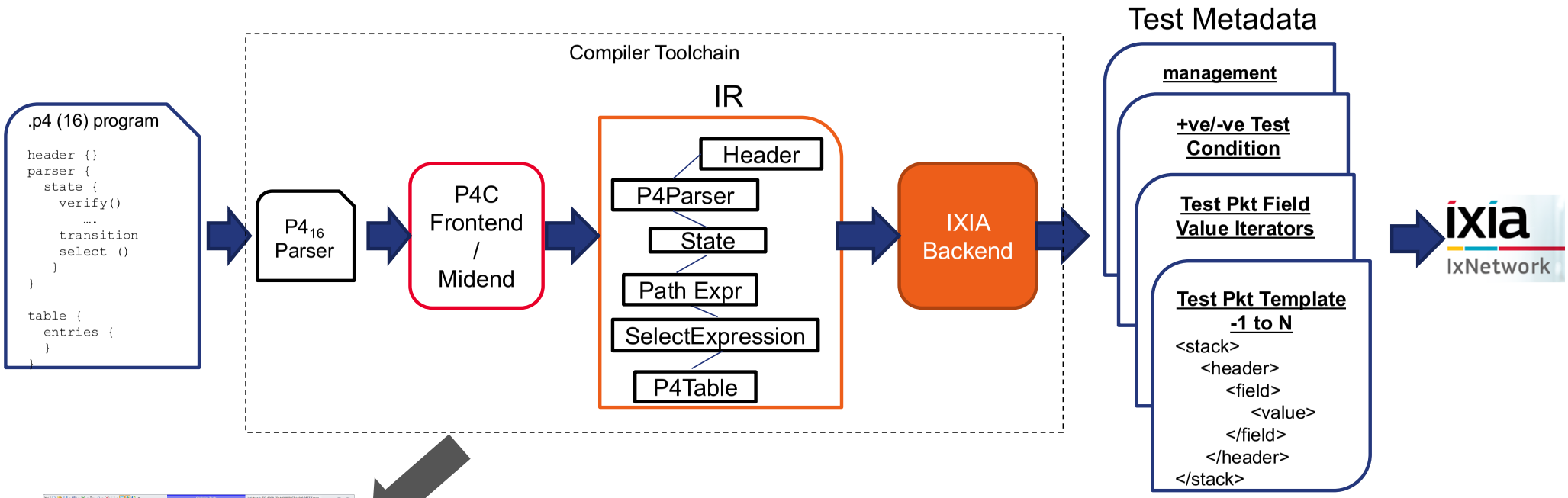


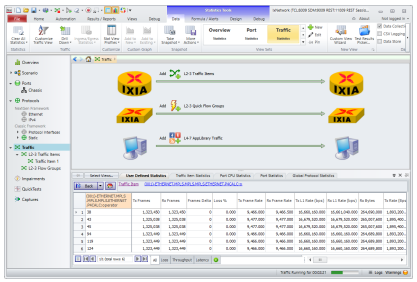
What did we do?

Enhancing IxNetwork to be P4-Aware

- ✓ Create a new backend for the p4c compiler: p4c-ixia. Output is test-case metadata
- ✓ Enhance IxNetwork to embed and launch p4c-ixia and to import the test-case metadata
- ✓ Enhance IxNetwork to translate test-case metadata into test data streams utilizing our packet engines
- ✓ Existing load modules (physical and virtual) are already highly programmable and largely protocol-agnostic. *No modifications were required on the packet engines.*
- ✓ This also allows both our physical and virtual packet testers to support p4 testing.

Architecture



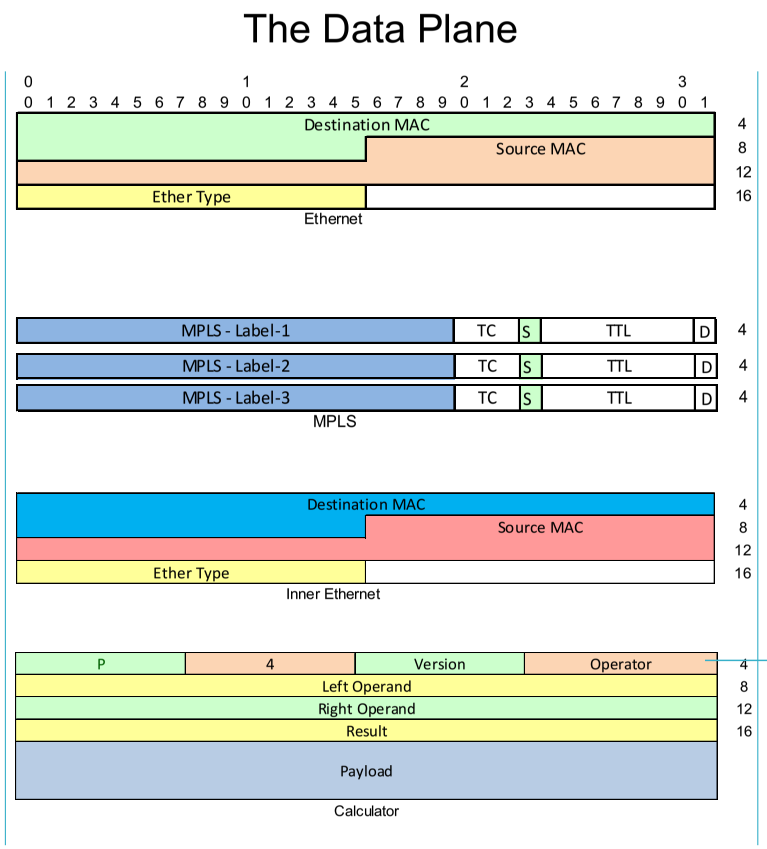


p4c-ixia embedded within IxNetwork

Metadata Packet Structures & Field Values:

- All possible valid sequence of protocol headers (packet templates).
- “Header Stacks” information (eg: multiple MPLS labels)
- Erroneous Packets (eg: hitting the reject rules, exceeding the boundary conditions)
- Packet fields values to test the limit of “Verify” condition
- Packet structure and field values needed to execute “Key Set” for “Select”
- Dealing with constant entries in “P4 Table”.

Calculator Protocol – An arbitrary data-plane as test case

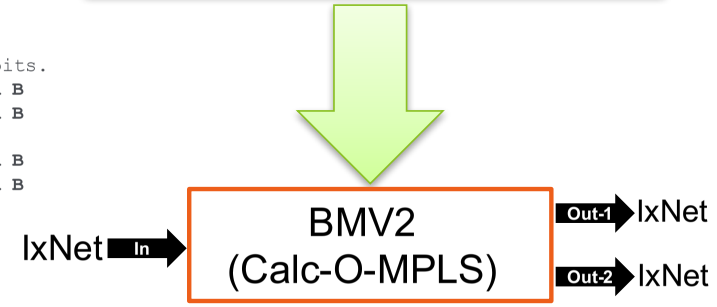


- Header stack
- Validation : pkts with 1~3 labels

```
 * All headers, used in the program needs to be assembled into a single struct.
 * We only need to declare the type, but there is no need to instantiate it,
 * because it is done "by the architecture", i.e. outside of P4 functions
 */

struct headers
{
    @name("ethernet")
    ETHERNET   ethernet;
    @name("p4calc")
    P4CALC     p4calc;
    @name("mpls")
    MPLS[3]    mpls;
    @name("inner_ethernet")
    ETHERNET   inner_ethernet;
}


struct ingress_metadata_t
{
   bit<1> flag;
}

struct metadata
{
    @name("ingress_metadata")
    ingress_metadata_t ingress_metadata;
}

/*************************************************************************
                            P A R S E R
 *************************************************************************/

parser PacketParser(packet_in packet, out headers hdr, inout metadata meta, inout standard_metad
{
    @name("start") state start
    {
        transition parse_ethernet;
    }

    @name("parse_ethernet") state parse_ethernet
    {
        packet.extract(hdr.ethernet);
        transition select(hdr.ethernet.etherType)
        {
            0x8847          :   parse_mpls;
            default         :   parse_reject;
        }
    }

    @name("parse_mpls") state parse_mpls
```

OPERATOR is an operation to Perform. It is of 8 bits.

- '+' (0x2b) **Result=Left Operand + Right Operand B**
- '-' (0x2d) **Result=Left Operand – Right Operand B**
- '&' (0x26) **Result=Left Operand & Operand B.**
- '|' (0x7c) **Result=Left Operand | Right Operand B**
- '^' (0x5e) **Result=Left Operand ^ Right Operand B**



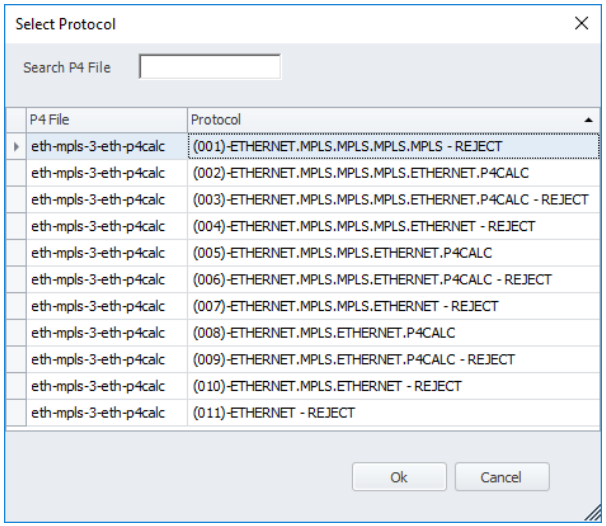
https://github.com/p4lang/tutorials/blob/master/P4D2_2017_Spring/exercises/calc/solution/calc.p4

KEYSIGHT TECHNOLOGIES

Video Demonstration

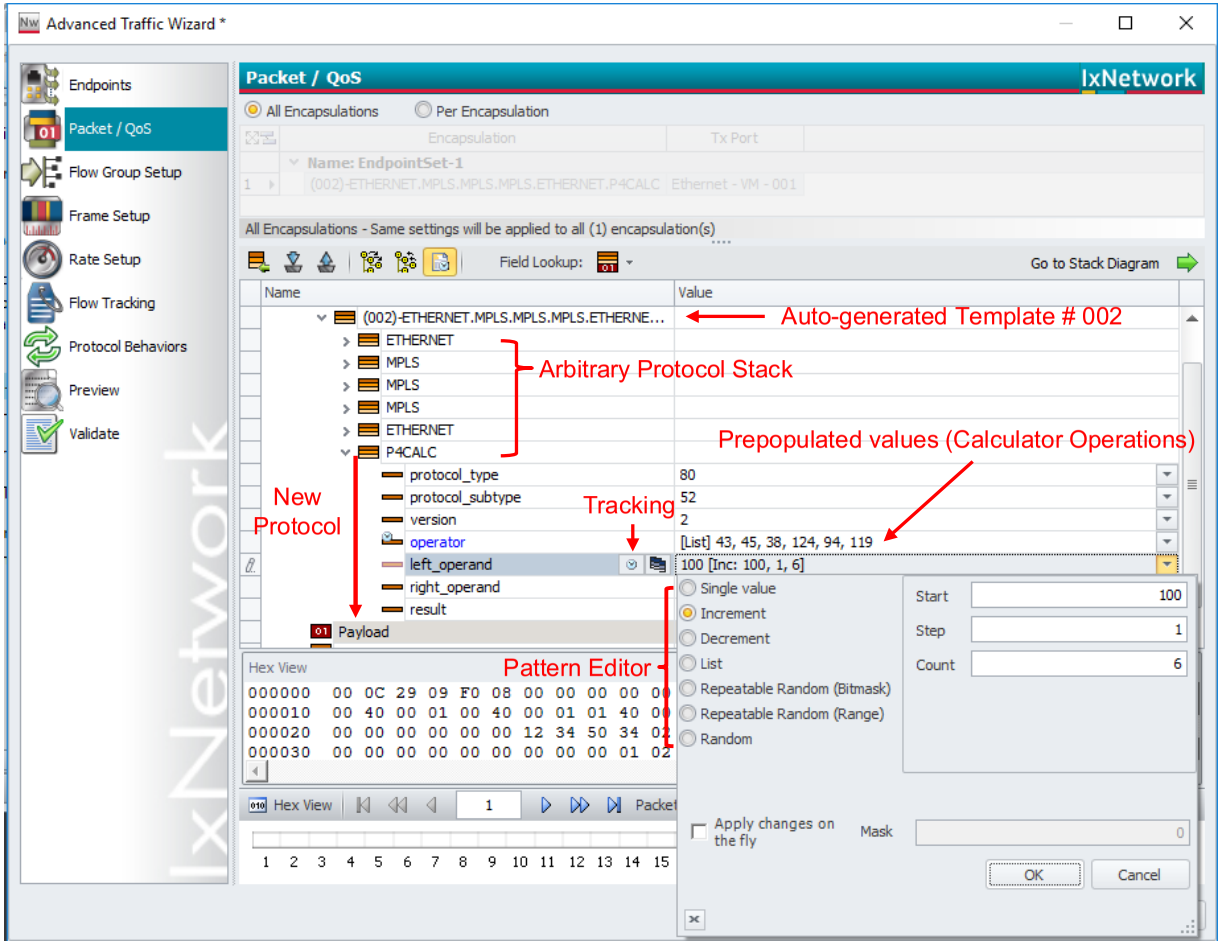
Results : Templates (Positives & Negatives)

Stack name	Details
"(001)-ETHERNET.MPLS.MPLS.MPLS.MPLS - REJECT "	Rejected as 4th MPLS stack not supported.
"(002)-ETHERNET.MPLS.MPLS.MPLS.ETHERNET.P4CALC"	
"(003)-ETHERNET.MPLS.MPLS.MPLS.ETHERNET.P4CALC - REJECT"	Rejected by p4calc version (0x503402 accepted type)
"(004)-ETHERNET.MPLS.MPLS.MPLS.ETHERNET - REJECT"	Rejected by inner eitherType (0x1234 accepted type – calc protocol)
"(005)-ETHERNET.MPLS.MPLS.ETHERNET.P4CALC"	
"(006)-ETHERNET.MPLS.MPLS.ETHERNET.P4CALC - REJECT"	Rejected by p4calc version (0x503402 accepted type)
"(007)-ETHERNET.MPLS.MPLS.ETHERNET - REJECT"	Rejected by inner eitherType (0x1234 accepted type – calc protocol)
"(008)-ETHERNET.MPLS.ETHERNET.P4CALC"	
"(009)-ETHERNET.MPLS.ETHERNET.P4CALC - REJECT"	Rejected by p4calc version (0x503402 accepted type)
"(010)-ETHERNET.MPLS.ETHERNET - REJECT"	Rejected by inner eitherType (0x1234 accepted type – calc protocol)
"(011)-ETHERNET - REJECT"	Rejected by outer eitherType (0x8847 accepted type)



Results: What does the Ixia Traffic Engine see & do ?

- ✓ User friendly mechanism to vary any protocol fields.
- ✓ Use Ixia's powerful pattern editor to vary the fields. Underneath Ixia UDF(s) are used to support variation.
- ✓ Flexibility of any fields to track (including the new protocol) at Line rate.
- ✓ Ingress and Egress tracking support.
- ✓ Track on meta data (Frame size, Flow Group etc.).
- ✓ Facility to utilize the latency bin(s)
- ✓ Flow Grouping - lowest level of control on Frame rate / size / start & stop

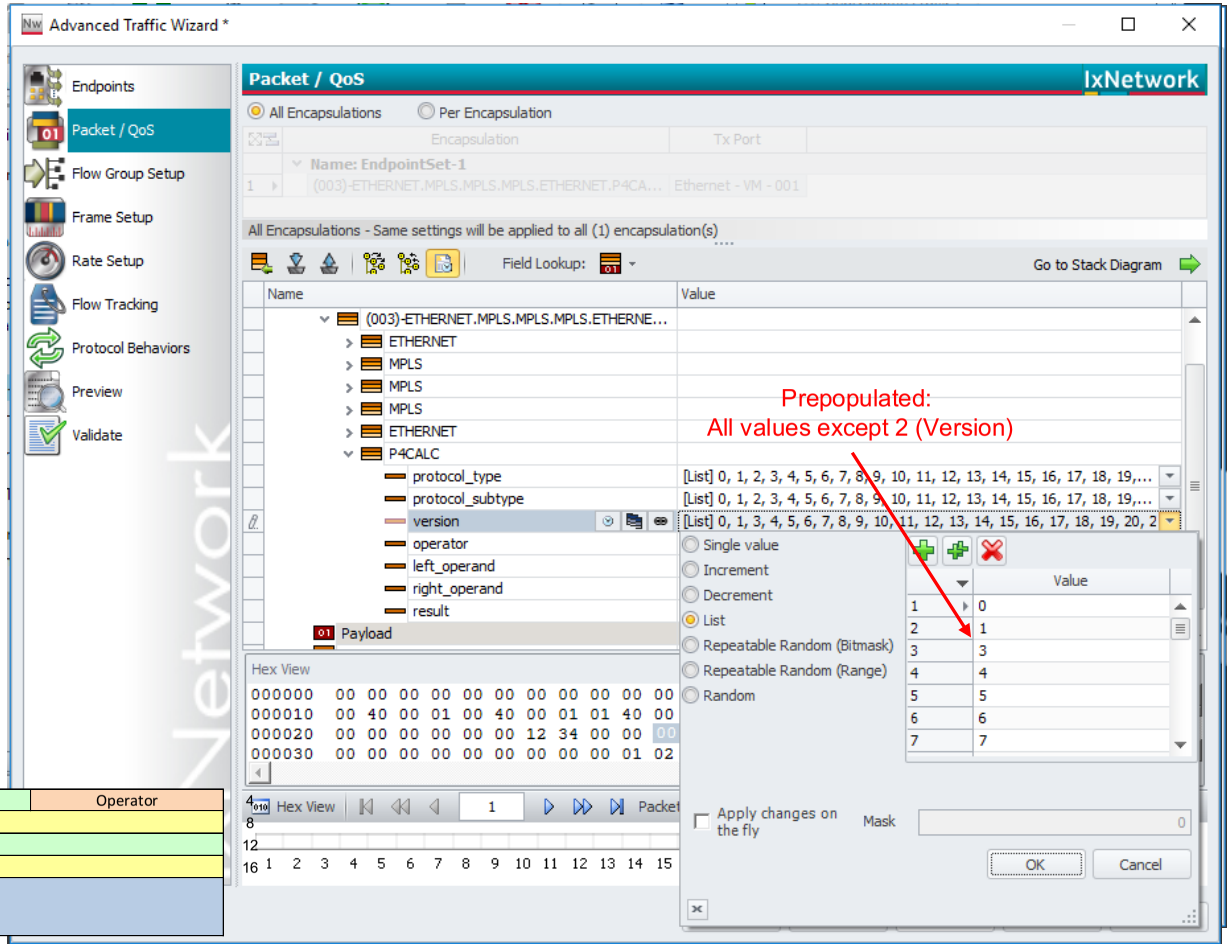


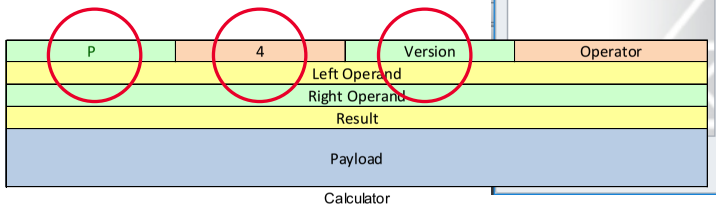
In this way we achieve a protocol independent "protocol test tool"

KEYSIGHT TECHNOLOGIES

Invalid field values (for negative test case 003)

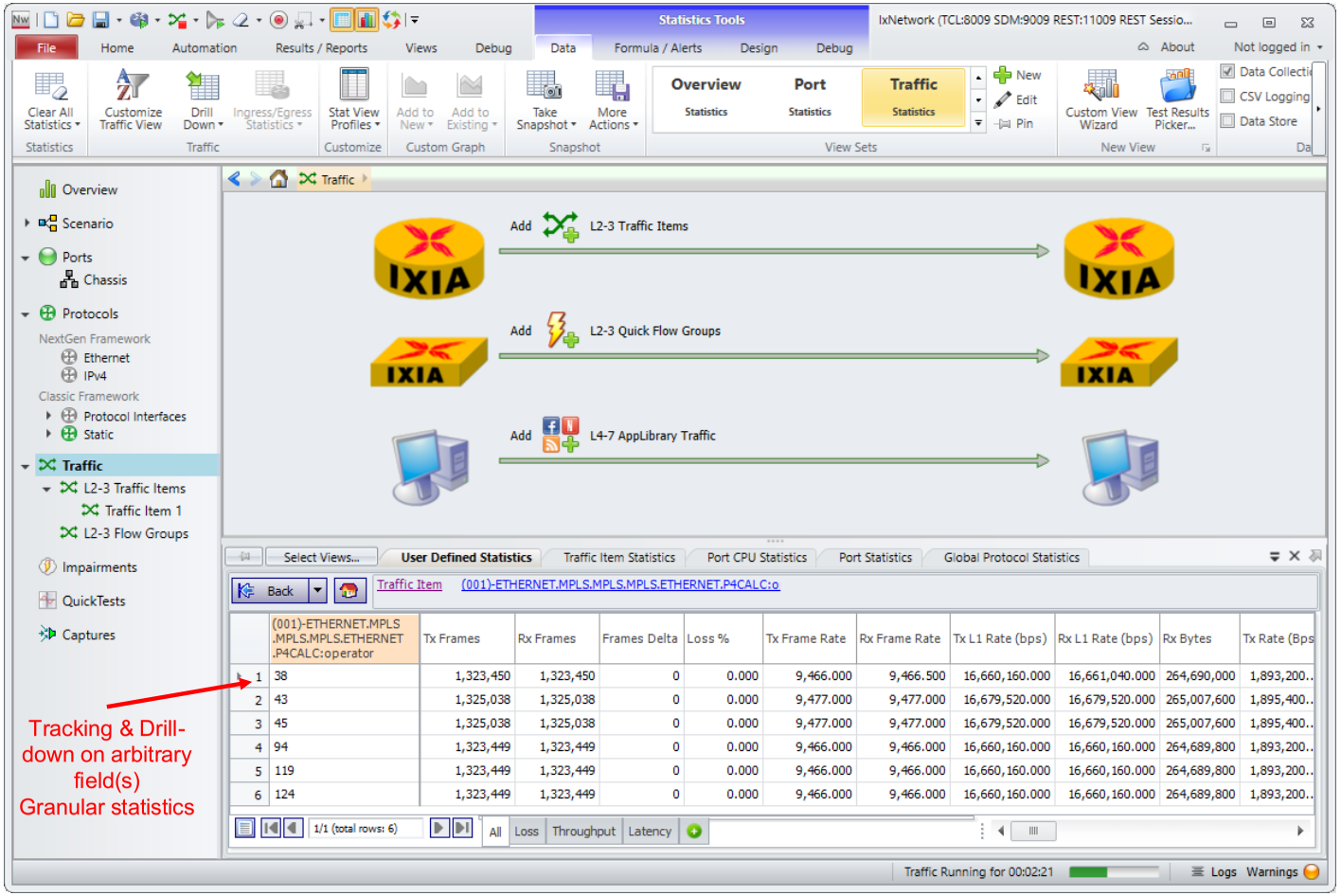
- ✓ Fields are pre-populated with invalid values.
- ✓ For Calculator Protocol, type should be ASCII ‘P’ (decimal 80) and Subtype should be ASCII ‘4’ (decimal 52).
- ✓ Fields are pre-populated with all 8-bit values *except* the valid ones.
- ✓ Pattern Editor customization
- ✓ Similarly, for version field, field is pre-populated with all values other than 2, to verify target behavior for reject scenario.
- ✓ And so forth…





Results : Tracking based on arbitrary fields

- ✓ Packet generation at Line rate.
- ✓ Drill down statistics based on the tacking fields (including arbitrary fields in arbitrary protocol)
- ✓ Simulates thousands of packets in specific order and verify correct order and latency

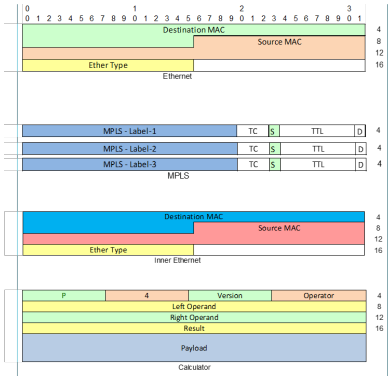


What's Next ?

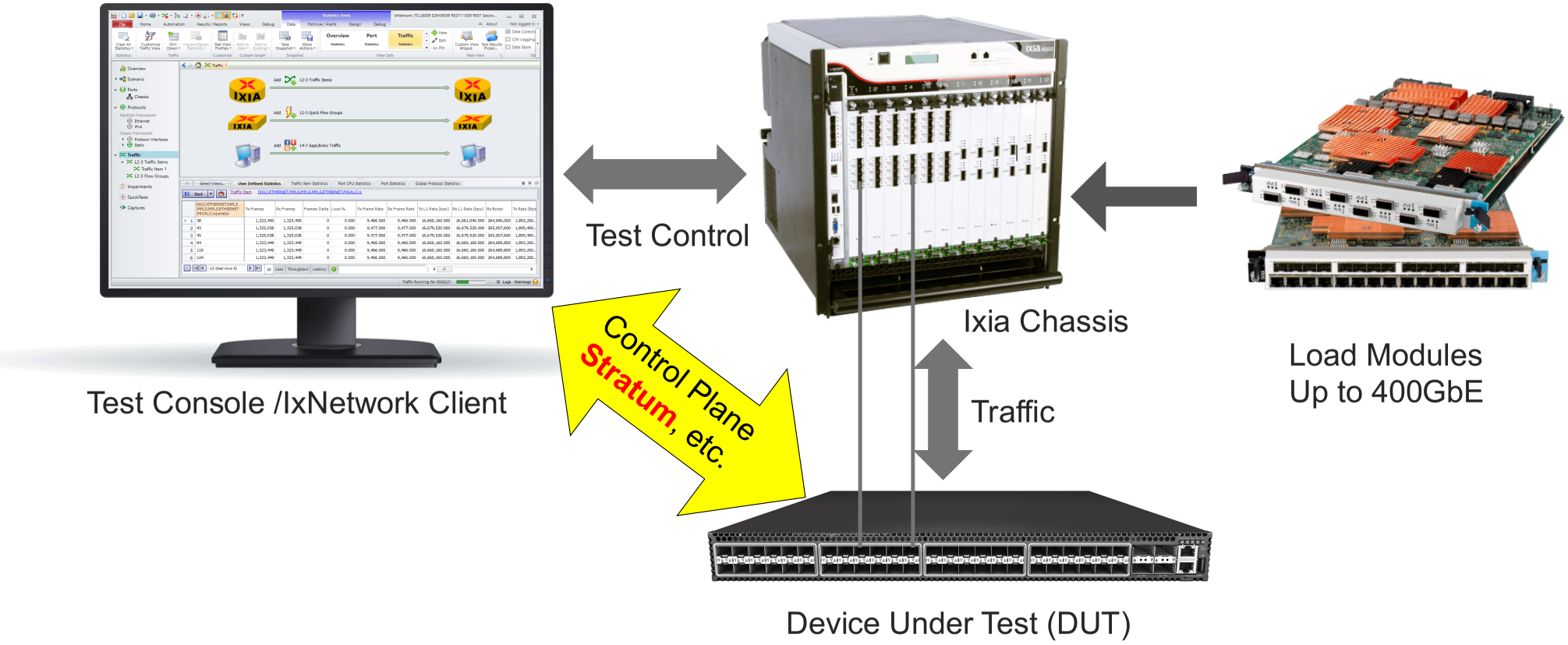
- ✓ Focus on testing, stability and react to community feedback.
- ✓ Automatic packet decoder

```
⊞ Frame 23: 200 bytes on wire (1600 bits), 200 bytes captured (1600 bits) on interface 0
⊞ Ethernet II, Src: aa:00:00:00:00:01 (aa:00:00:00:00:01), Dst: 00:0c:29:09:f0:08 (00:0c:29:09:f0:08)
⊞ MultiProtocol Label Switching Header, Label: 10016, Exp: 0, S: 0, TTL: 64
⊞ MultiProtocol Label Switching Header, Label: 20016, Exp: 0, S: 0, TTL: 64
⊞ MultiProtocol Label Switching Header, Label: 30016, Exp: 0, S: 1, TTL: 64
⊞ Ethernet II, Src: aa:00:00:00:00:01 (aa:00:00:00:00:01), Dst: 00:0c:29:09:f0:08 (00:0c:29:09:f0:08)
⊟ Calculator Protocol
    Version: 2
    Operator: PLUS (0x2b)
    Left Operand: 100
    Right Operand: 10
    Result: 110
```

- ✓ Stateful Fuzzing of arbitrary protocol



Future possibility - Control Plane Integration



Questions?