Network Coding Architecture

- Use cases, protocols and building blocks -

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Overview

- Goal: Present ideas for Network Coding Architecture
- Ideally, this architecture would accommodate all possible use cases – not practical
- Start with several use cases with potential for practical applications, such as existing implementations
- Foster innovation in protocol design and use cases
- Design principles:
  - Protocol instances constructed from building blocks (BB)
  - BBs have common functionality between use cases
  - Try to reuse existing BBs

Note: Some of these ideas are still under discussion among authors. Here we submit them to discussion in NWCRG.

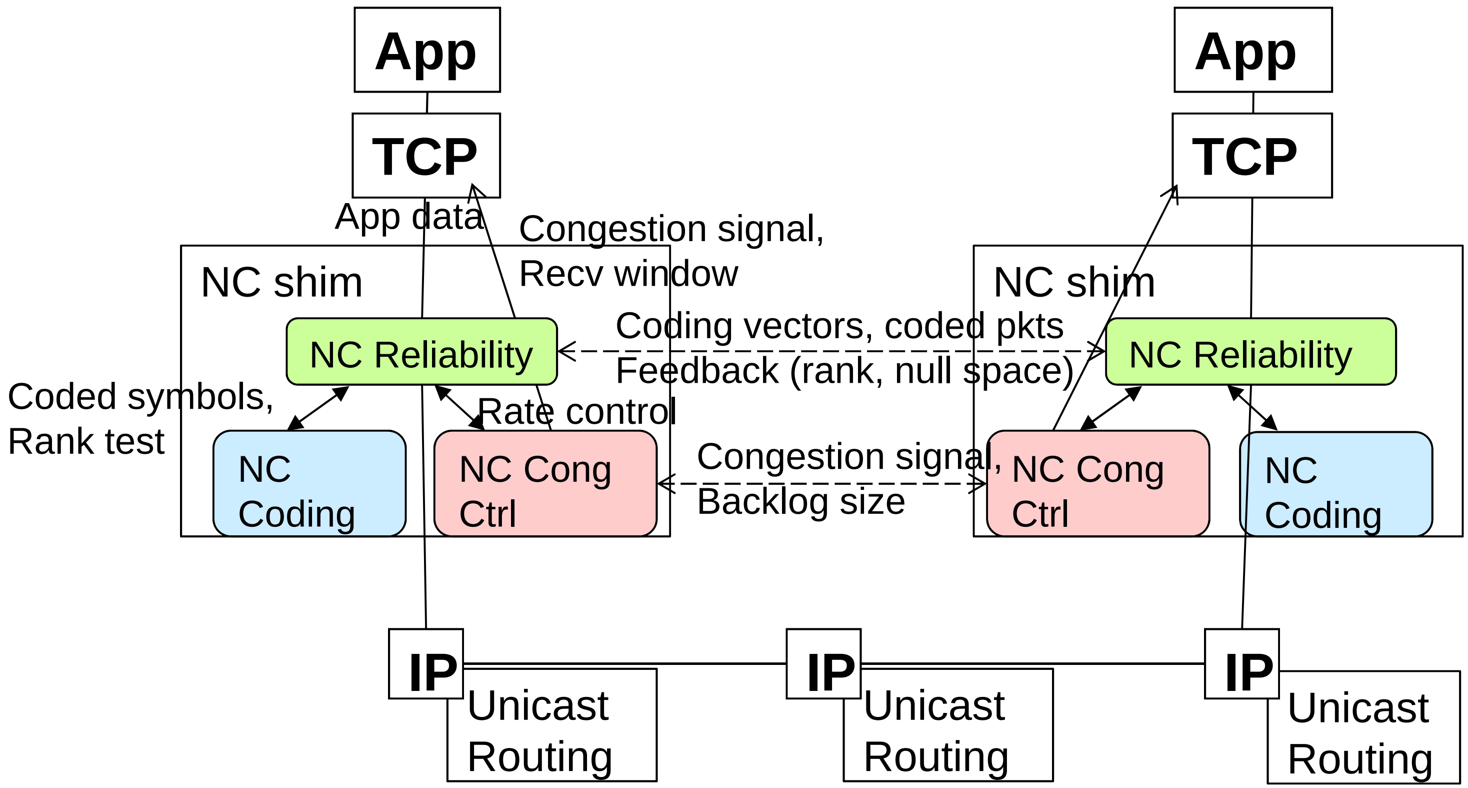
Use Cases

1. NC shim* layer - under TCP, UDP, SSH
2. NC transport, in-net coding
3. NC transport over overlay network
4. NC shim* under tunnel (MPLS, IPsec)
5. Coded TCP (or TCP-like) over disjoint paths
6. NC content dissemination at application layer

(*) Shim: a non-traditional layer, usually between routing and transport

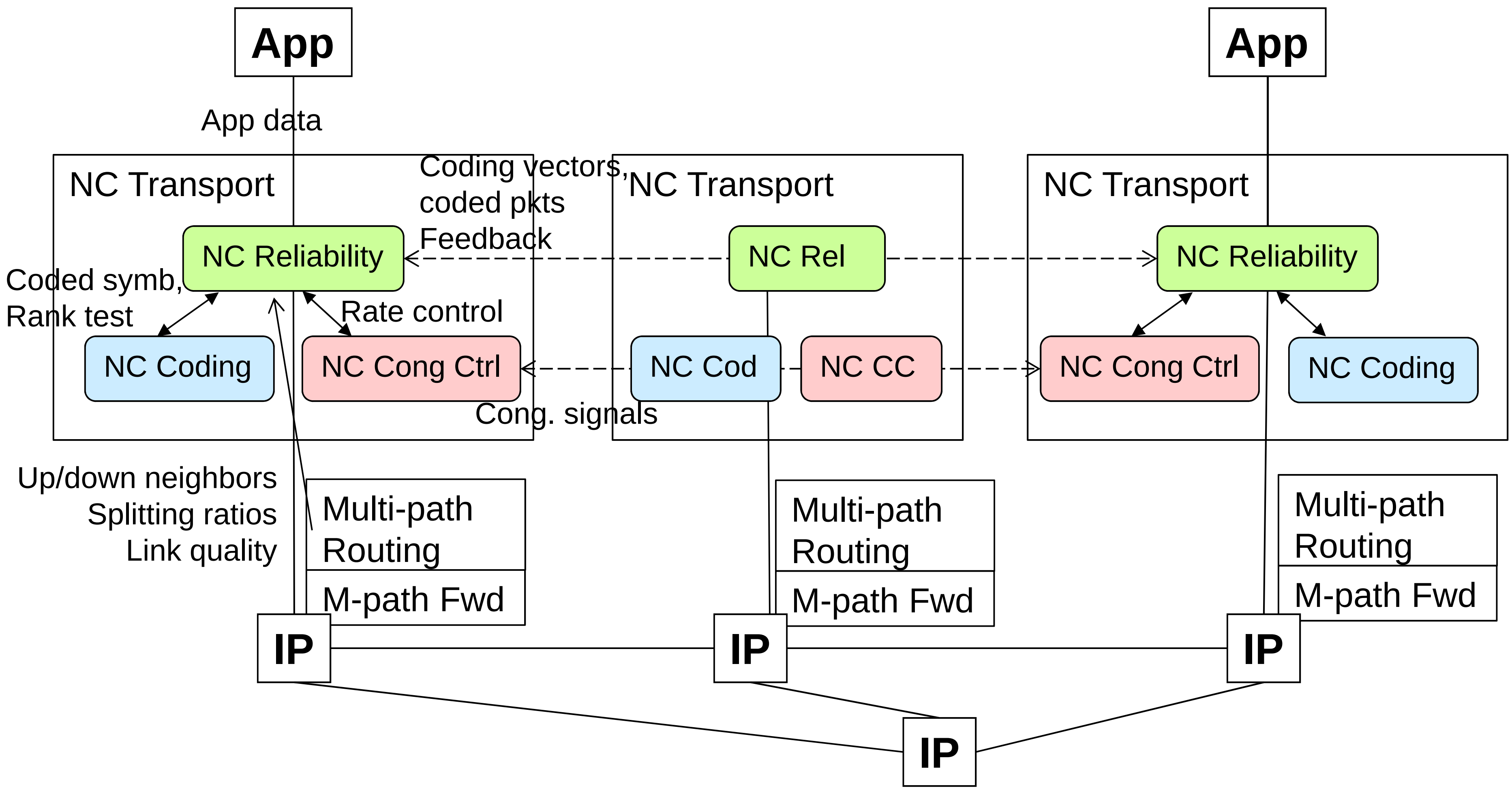
Note: This is not an exhaustive list, but hopefully a large enough set to help identify key building blocks that can be reapplied for different use cases.

Use Case 1: NC Shim Layer – under TCP, UDP, SSH



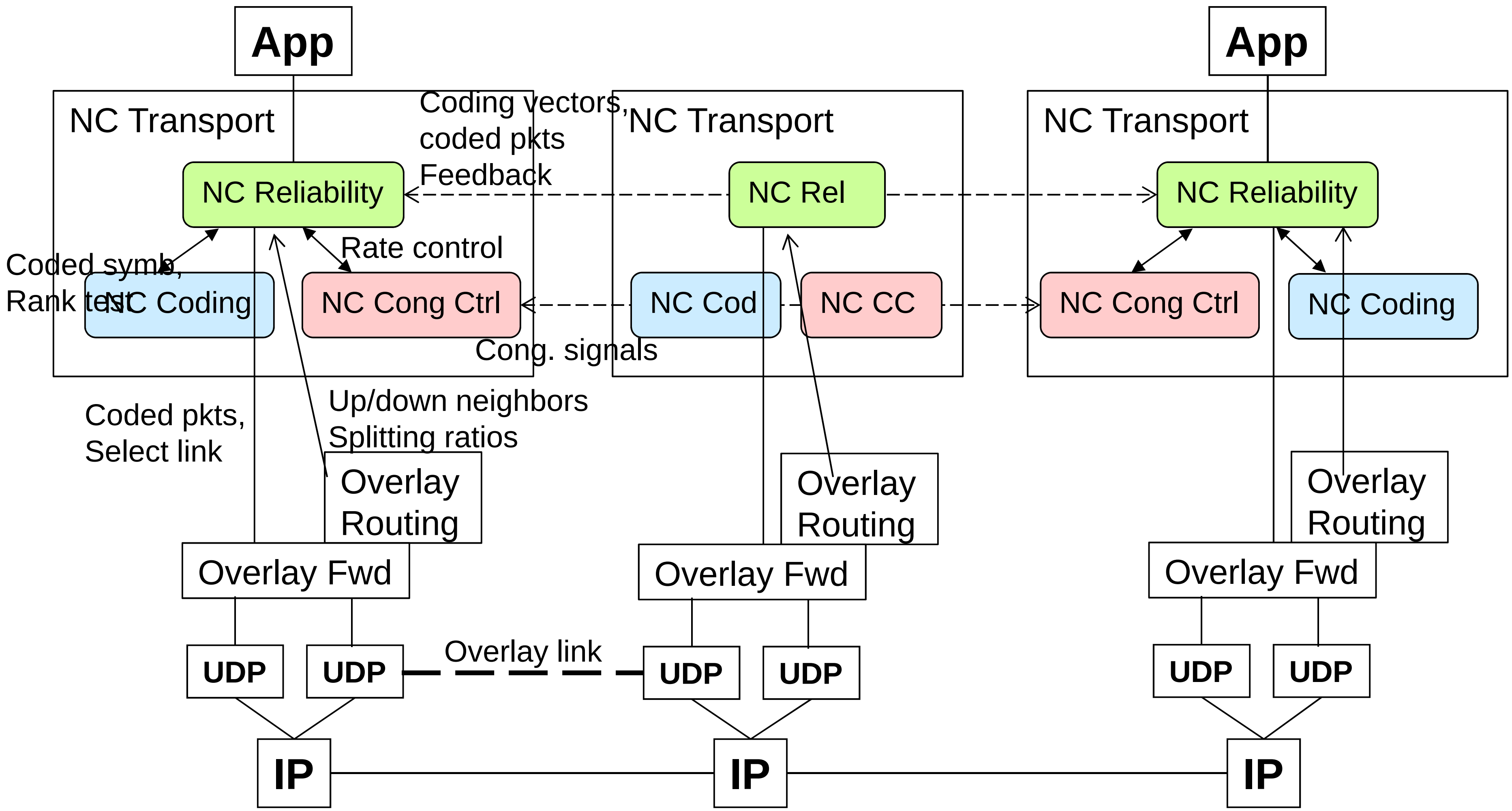
- Coding: end-end. Passes CC signaling.
- Optional: in-network re-coding.
- Coding nodes determined by: static configuration, routing or control signaling.
- Usage: reliability, similar to source coding.

Use Case 2: NC Transport, In-Network Coding,



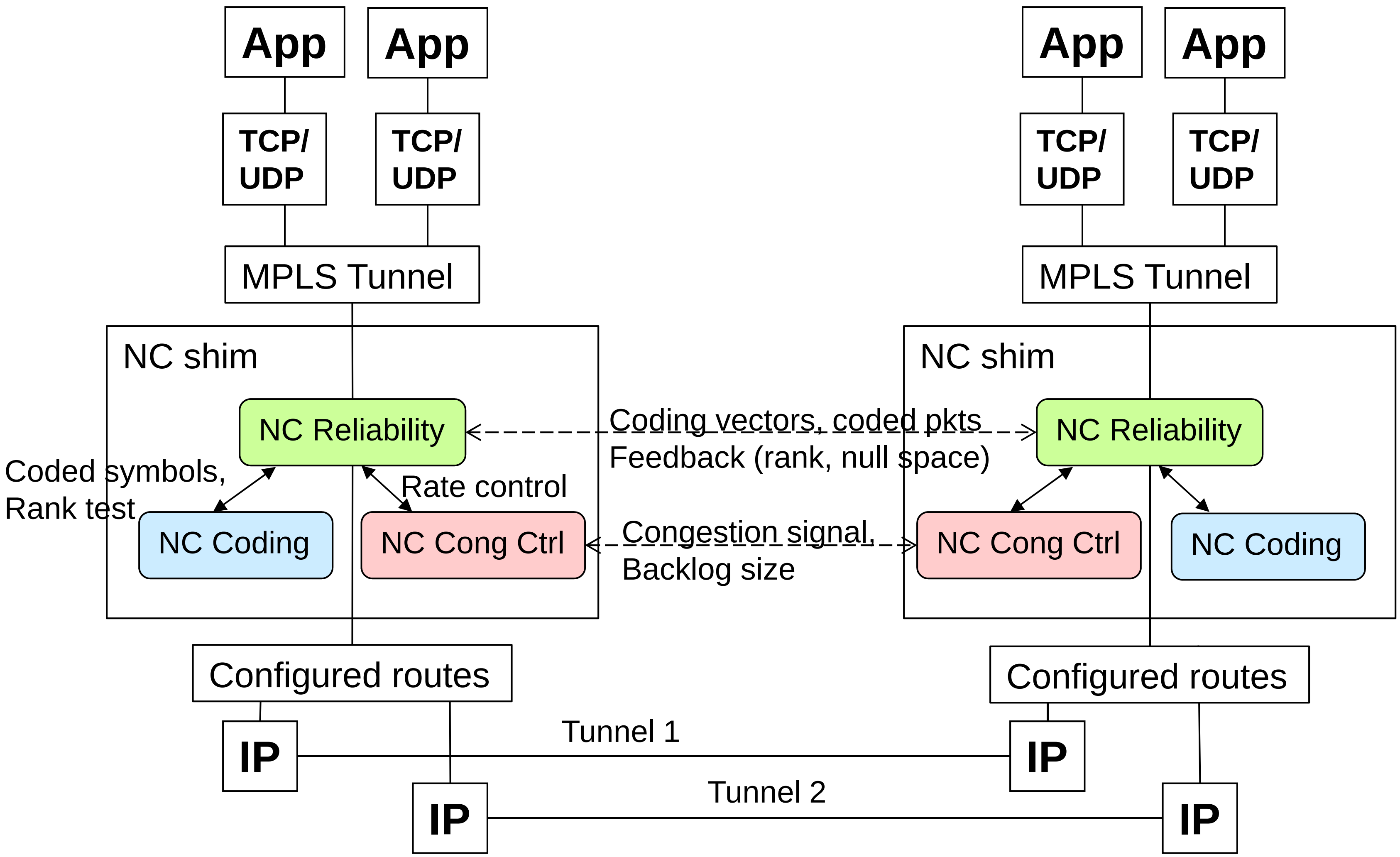
- Assisted by multi-path (subgraph) routing
- Usage: reliability, resilience to link and node outage.
- Supports both Unicast and Multicast

Use Case 3: NC Transport over Overlay Network



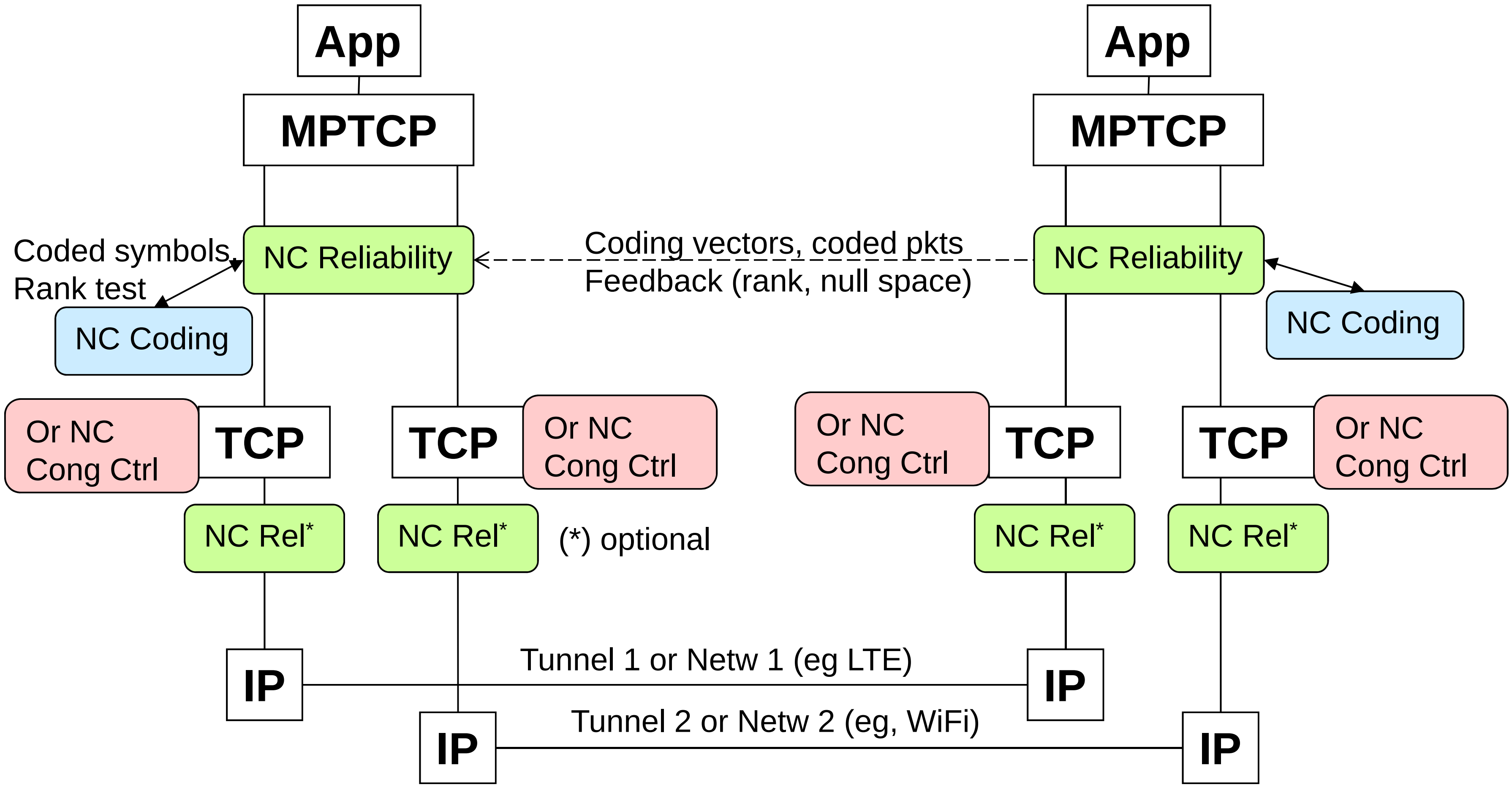
- Overlay links can be reliable (TCP) or unreliable (UDP).
- Requires both reliability and congestion control functions
- Usage: reliability, resilience to link and node outage, anonymity.

Use Case 4: NC Shim under Tunnel (MPLS, IPsec)



- Usage: Provides reliable forwarding under MPLS tunnel
- Assumes configured IP tunnels or routes under NC shim

Use Case 5: Coded TCP (or TCP-like) over Disjoint Paths



- Coding: over all paths
- Congestion control: separate for each path

Some terminology

- input flow terminology
  - an **input flow** enters a NC protocol instance
  - an input flow contains **input packets**
    - **a packet may be a UDP datagram, an IP datagram, a frame, an application data unit, a file slice, etc.**
  - an input packet contains **input symbol**(s)
    - **plus protocol headers, control information, etc.**
    - **packet/symbol mapping can be 1⇔1 or 1⇔multiple (not assumed to be frequent) or multiple⇔1 (if fragmented, when needed by the use-case)**
  - an input symbol can be a **source** symbol or a **repair** symbol (encoded one or more times)

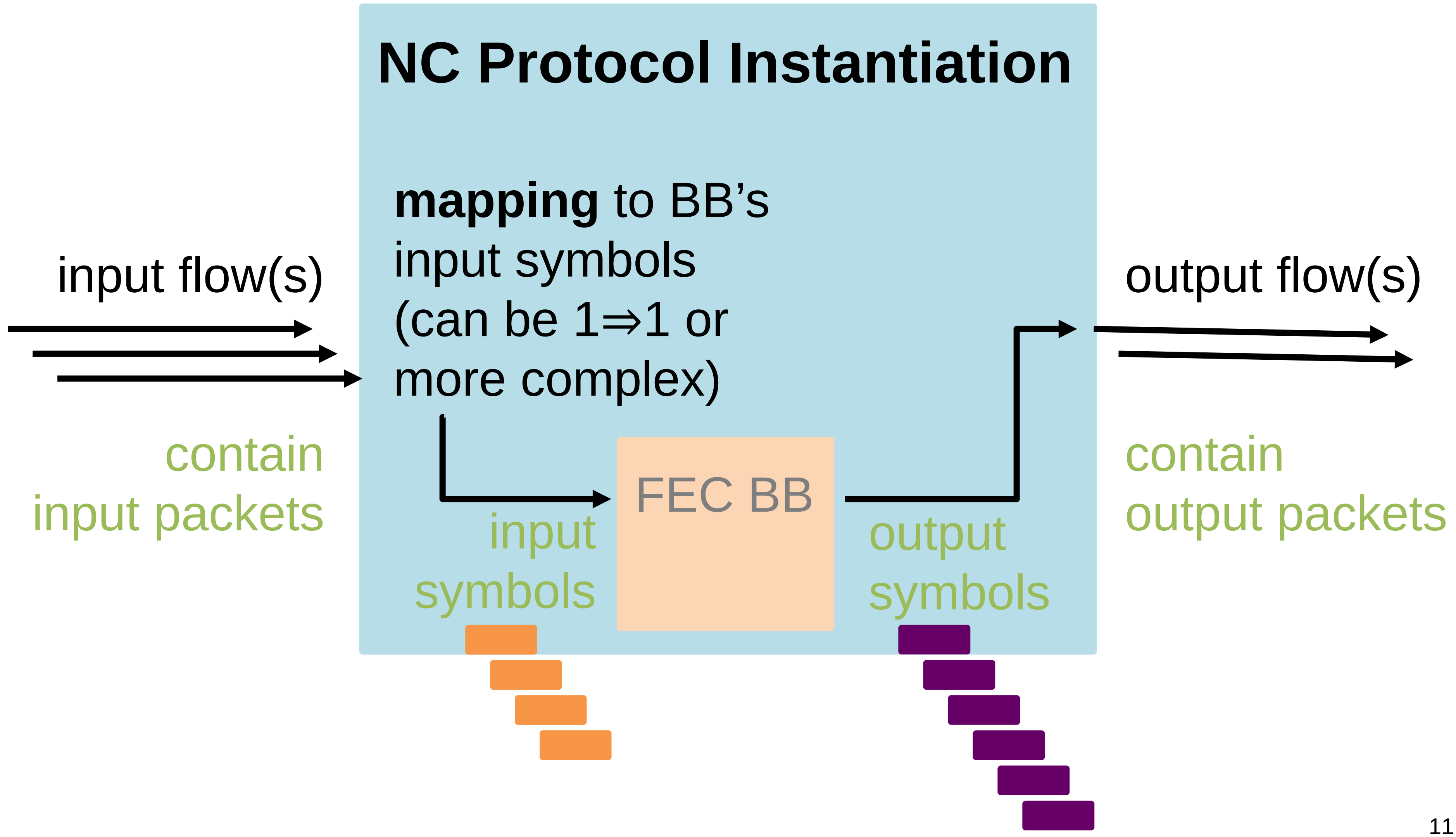
Some terminology… (cont')

- output flow terminology
  - output flow/packet are similar
  - an output symbol is an **encoding symbol**, i.e., either a **source** symbol (at a decoder or in case of a systematic FEC) or a **repair** symbol

- NB: "encoding symbol" definitions in current RFC
  - [RFC 6363]
    - Encoding Symbol: Unit of data generated by the encoding process. With systematic codes, source symbols are part of the encoding symbols.
  - [RFC 5052]
    - Encoding symbol: A source symbol or a repair symbol.

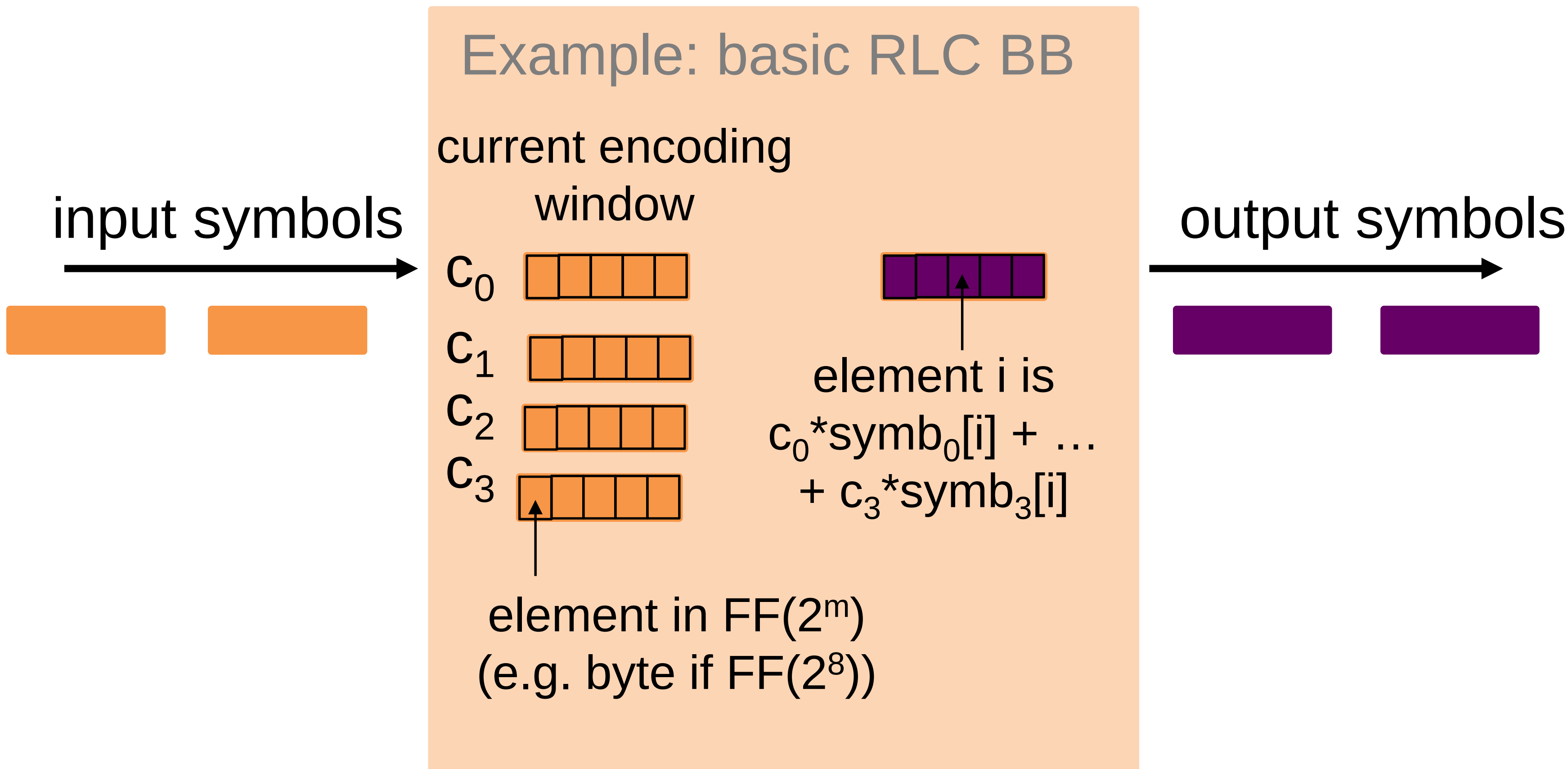
Close-up on the FEC building block

- let's see the FEC BB terminology



An example

- let's consider an RLC FEC BB
  - it's just an example, other FEC BB will be considered in future
  - example: encoding side



More about FEC terminology

- FEC scheme (fully specified, see RFC 5052)

FEC Scheme

=

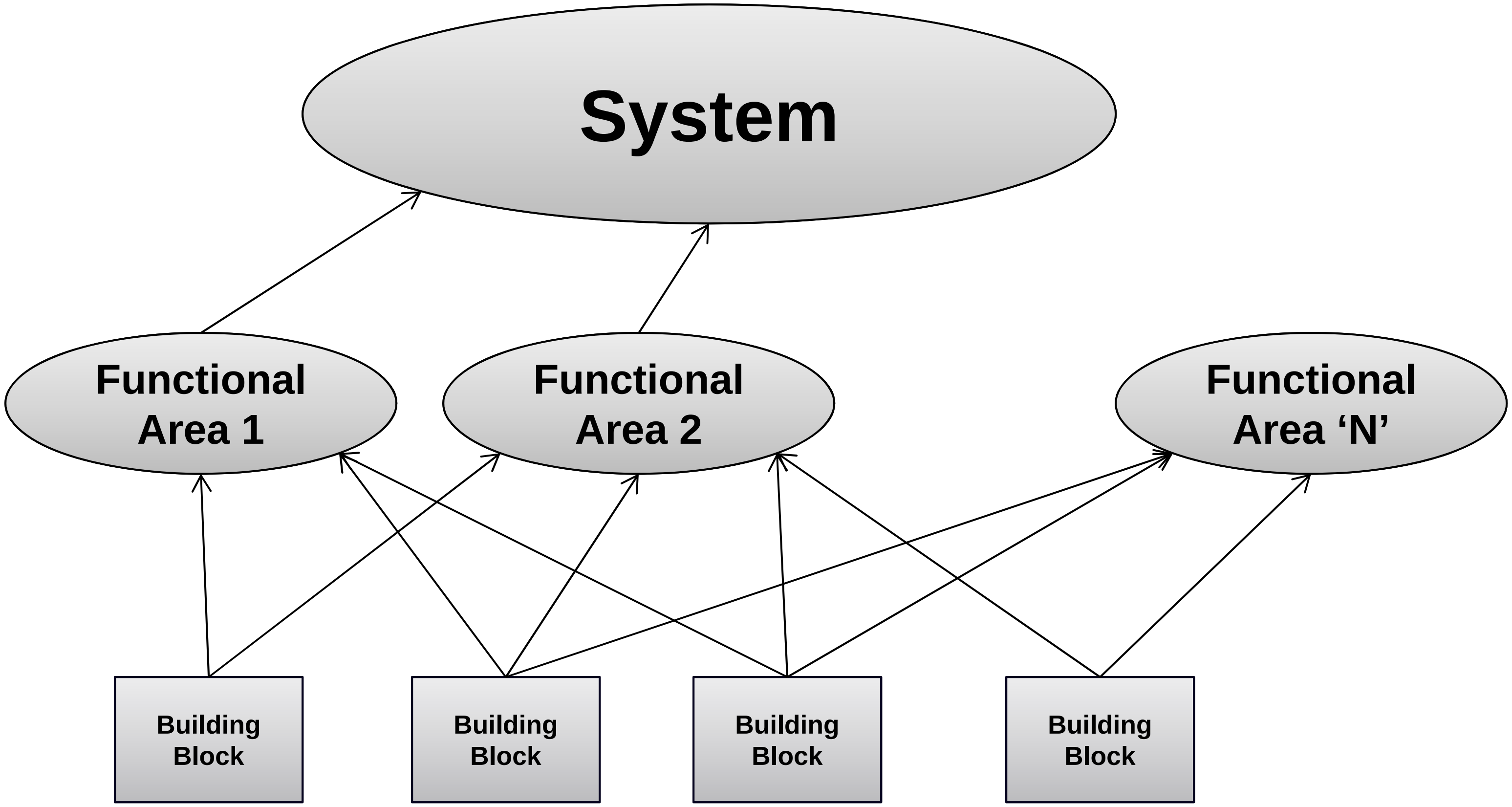
{identifier + code specifications + signaling }

- each scheme is uniquely **identified** (IANA registry)
  - **FEC Encoding ID** ex. 5 for Reed-Sol. over $FF(2^8)$ in the context of RMT
- all the **code details** are specified non ambiguously
  - interoperability is a MUST
- **signaling** enables encoder/decoder synchronization, for a given object transfer

More about FEC terminology… (cont')

- yes, we need a FEC Encoding ID
  - for instance:
    - **FEC Encoding ID 100 binary RLC**
    - **FEC Encoding ID 101 RLC over GF(2^4)**
    - **FEC Encoding ID 102 RLC over GF(2^8)**
    - **FEC Encoding ID 103 Structured RLC**
    - **FEC Encoding ID 104 another FEC solution…**
    - **NB: ID 100 can also refer to RLC over GF(2^m), where m is carried in the signaling part… It works too!**
  - this FEC Encoding ID points to a specific FEC BB and a specific way of doing signaling
    - **so that a NC instance knows exactly how to process it**

Network Coding System Decomposition



Network Coding Functional Areas & Building Blocks 1/3

- NC Coding – all coding operations
  - E.g., encoding, decoding, test for “innovative”, rank, null space
  - Using operations such as finite field and linear transformations

- NC Reliability – data and control to support reliable transfer
  - Includes reliability logic (end-to-end and/or hop-by-hop), coding vectors, feedback.
  - May be subdivided in FEC BB + coefficient BB + header BB

Network Coding Functional Areas & Building Blocks 2/3

- NC Congestion Control – controls transmission rates
  - Flavors: unicast CC, multicast CC, subgraph CC
  - Should try to use algorithms developed in other WGs when possible, such as TCP-Friendly based on the PFTK formula [1], as in NORM [2]
  - Subgraph CC - most likely new

[1] J. Padhye, V. Firoiu, D. Towsley, J. Kurose, *"Modeling TCP Throughput: A Simple Model and its Empirical Validation"*, ACM SIGCOMM 1998.

[2] B. Adamson, C. Borman, M. Handley, J. Macker, *"NACK-Oriented Reliable Multicast (NORM) Transport Protocol"*, RFC5740.

Network Coding Functional Areas & Building Blocks 3/3

- Multi-path routing, multi-path forwarding
  - Related to NC reliability BB through: splitting ratios (fwd factors), up/down neighbors, link quality
  - Most likely: augment existing routing and fwd protocols

- Security – First option: rely on existing solutions
  - Unless creating a new security protocol with NC as essential part
  - Can do: pollution detection at the packet level, without decoding, or detection and correction at a layer that decodes

Conclusions, Issues and Open Questions

- Modular reuse approach based on BB seems to work: all use cases presented can be built using a very small number of BBs
- Architecture of use cases needs (a lot of) work to be mapped/ integrated into the IETF layers/ areas.
- NC Coding and NC Reliability BBs – are core elements
- Congestion Control – can use existing algorithms
  - CC for general subgraphs does not exist
  - NC under TCP can raise questions about fairness – some answers exist. Need to clarify.